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Effects of Applied Nitrogen and Phosphorus on Native Grasslands in the Northern Great Plains

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EFFECTS OF APPLIED NITROGEN AND PHOSPHORUS ON NATIVE GRASSLANDS IN THE NORTHERN GREAT PLAINS

BY

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ON NATIVE GRASSLANDS IN THE NORTHERN GREAT PLAINS

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser Date

Head, Plant Science Department Date

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INTRODUCTION

The majority of the grazing lands in the Northern Great Plains are native grasslands. In some areas profits derived from these grasslands may best be increased by complete renovation and reseeding. However, many of these grasslands can be improved by practices such as deferred grazing, interseedings, rotational grazing and fertilization.

This study involves the evaluation of one of these practices, nitrogen and phosphorus fertilization. It is a study that is to provide basic information which can be used to determine the economic feasibility of grassland fertilization.

The purpose of this study was (1) to determine whether significant yield increases could be obtained from nitrogen fertilizer application on native grassland in the Northern Great Plains climate, (2) to determine the extent to which residual nitrogen increases yields in succeeding growing seasons, (3) to determine whether the application of a light rate of phosphorus could produce significant yield increases in soils that are very low in soil test phosphorus levels, (4) to determine the effects of date of nitrogen application on yield and (5) to determine the effects of various nitrogen and phosphorus levels and the effects of varying dates of nitrogen application on the content of protein, phosphorus, calcium, magnesium, sulfur, potassium, and nitrates in the forage.

LITERATURE REVIEW

Previous work with nitrogen and phosphorus fertilization of grasslands has demonstrated that expected yield increase from fertilizer at different times and different places is extremely variable and is dependent upon many factors. Therefore, in order to conduct a study of fertility responses one must determine the possible effects of each of these factors in order to evaluate completely the resultant data.

This literature review was aimed at (1) the factors that determine whether a response to the addition of major nutrients, especially nitrogen and phosphorus, can be expected, (2) what constitutes a response, (3) residual effects of N-P fertilizer materials and factors determining them and, (4) some liabilities encountered with the addition of N-P fertilizers giving special emphasis to weed increases.

Major Factors Determining Responses To Nitrogen and Phosphorus Fertilization

Climate

Moisture

Moisture is a foremost factor. Experiments in western South Dakota on crested wheatgrass (*Agropyron desertorum*) and bromegrass (*Bromus inermis*) mixtures by Thomas and Osenbrug (36) demonstrated that a non-linear relationship exists between seasonal precipitation and yield. They found that within the seasonal (April--May-June) precipitation limits of 7.6 and 25.4 cm all applications of nitrogen fertilizer significantly increased yields over non-fertilized plots.

Hubbard and Mason (11) conducted fertilization experiments on native grasslands on four sites in British Columbia, Canada, dominated by bluebunch wheatgrass (*Agropyron inerme*), needle and thread grass (*Stipa comata*) and Columbia needlegrass (*Stipa columbiana*). The average annual rainfall during the five year study on the three sandy loam sites was 24.9, 29.7 and 33.5 cm respectively, and was 30.6 cm on the silt loam site. At the end of five years they found that productivity was increased only on the least droughty site (the silt loam site) and this increase in yield was small.

Other studies in low rainfall areas including studies by Kay (16) on cheatgrass (*Bromus* spp.) ranges in California under 29.0 cm annual average precipitation and on cheatgrass and bluebunch wheatgrass ranges by Wilson, Harris and Gates (38) under 25.7-35.0 cm annual precipitation in Washington, have demonstrated that responses to nitrogen fertilization were variable and undependable where moisture levels were low.

On blue grama (*Bouteloua gracilis*)-western wheatgrass (*Agropyron smithii*)-needle and threadgrass range at Mandan, North Dakota, in an area averaging 45.5 cm of rainfall per year, Rogler and Lorenz (31) found annual applications of 34 kg N/ha nearly doubled yields (from 838 kg/ha to 1486 kg/ha) and 101 kg N/ha tripled yields (from 838 kg/ha to 2546 kg/ha) when averaged over the six year period.

Cosper and Thomas (8) in experiments on bromegrass-crested wheatgrass haylands in western South Dakota under 41.1 cm average annual rainfall, found that the efficiency of nitrogen fertilizer decreased as the supply of available moisture decreased.

Increased yields from fertilization have been attributed in part to water removal to greater depths in the soil. Black (4) noted that both crested wheatgrass and native stands of mixed western wheatgrass, blue grama and green needlegrass (*Stipa viridula*), did not use stored water below sixty cm without fertilizer or with phosphorus alone, while nitrogen or nitrogen plus phosphorus fertilized plots used water to greater than ninety cm indicating root proliferation to greater depths.

Water supplies in the upper 15.2 cm of a dense clay site were observed to be depleted more rapidly where fertility was high (24).

Temperature

Temperature is not to be overlooked in estimating the feasibility of fertilization (1). Much of the yield response noted in many plant species has been due to nitrogen added early in the season when mineral nitrogen from organic sources is being released too slowly to meet the demands of the plant. For plants making their initial growth later in the season in warm soils, nitrogen is less critical because mineralization of nitrogen is occurring at an increased rate, giving the plant a greater portion of its needed nitrogen. In the light of these facts it might be expected that proper nitrogen fertilization would produce greater responses on cool season grasses than warm season grasses.

Also, as temperatures increase, losses of applied nitrogen become greater. This will be discussed more thoroughly later in this review.

Vegetation

Vegetation and the initial condition of that vegetation will determine the magnitude of response one may expect from fertilization.

Smika, Haas and Rogler (32) compared the responses of crested wheatgrass, bromegrass and Russian wildrye (*Elymus junceus*) in a seven year study in which all grasses were cut near bloom. They showed that yields of forage were highest for crested wheatgrass, somewhat less for bromegrass and least for Russian wildrye. However, whereas 67 kg N/ha were sufficient for maximum production of crested wheatgrass and bromegrass, 101 kg N/ha were needed by the Russian wildrye for maximum production. Kilcher (17) found similar results in southern Saskatchewan when comparing crested wheatgrass, Russian wildrye, and intermediate wheatgrass (*Agropyron intermedium*), but at even lower nitrogen and phosphorus fertilizer levels than used by Smika, Haas and Rogler (32).

Generally, on sites of mixed botanical composition, it could be quickly seen that some species were capable of responding to commercial fertilizers much more rapidly than others.

At the Northern Great Plains Field Station at Mandan, North Dakota (31) on heavily and moderately grazed pastures dominated by blue grama, western wheatgrass, and needle and thread, western wheatgrass made the most rapid increase in vegetative growth and dominance under nitrogen fertilization. Blue grama was forced to decrease due to shading by western wheatgrass.

On a Kansas range dominated by big bluestem (*Andropogon gerardii*), Owensby et al. (25) found that 56 kg N/ha broadcast annually on July 1 increased yields and protein levels substantially. Reardon and Huss (29) found they could increase hay yields of little bluestem (*Andropogon scoparius*) by 50% to 72% with blended NPK fertilizers, even under droughty conditions at College Station, Texas. Both these studies indicate that nitrogen fertilization can be effective on warm season grasses.

Initial Nutrient Status of the Soil

Initial nutrient status of the soil with respect to the nutrient applied has been traditionally used to determine whether or not any given plant will respond to fertilization.

Read, (28) working with nine irrigated sites of bromegrass and alfalfa (Medicago sativa) mixtures, found that the quantity of sodium bicarbonate extractable soil P was related to fertilizer response. Phosphatic fertilizers increased the yield and phosphorus content of forage over that of unfertilized plots on soils with less than 10 ppm sodium bicarbonate extractable soil P, but not on soils with more than 20 ppm P. In comparison to the factor of soil texture, frequency of application of fertilizer and irrigation intensity had little effect on the relative response to the phosphatic fertilizers.

Black (4) noted substantial yield increases due to phosphorus application on mixed cool season native grasses and crested wheatgrass stands in Montana, but initial phosphorus contents of the soil were extemely low (1-2 ppm $NaHCO_3$ extractable P) and consequently, the control plots suffered from a phosphorus deficiency and produced very low yields.

At Newell, South Dakota (36), on soils with 7 ppm $NaHCO_3$ extractable P, it was found that significant bromegrass-crested wheatgrass yield responses to applied phosphorus could be obtained with high seasonal precipitation in this semi-arid climate when the quantity of phosphorus applied exceeded the soil phosphorus adsorption capacity. This was where 79 kg P/ha plus 179 kg N/ha were applied annually for four years of the six year study, or a total of 316 kg P/ha had been applied.

Generally, soil nitrogen content was less important in regard to the fertilizer nitrogen response than one might expect. Even on soils naturally high in organic nitrogen, significant and often very substantial forage and protein yields were observed with nitrogen fertilization (31, 8, 4).

Time of Nitrogen and Phosphorus Application

Time of fertilizer application in relation to the time of utilization by the grass may be another factor to consider in the light of the conditions of moisture, temperature, vegetation and other factors that control nitrogen and phosphorus availability and losses over time.

Under semi-arid climatic conditions in western South Dakota (36) where the April-May-June rainfall averaged 15.0 cm and temperature for the same period averaged 18.5°C, annual applications of nitrogen did not significantly increase yields over single applications of nitrogen. The results showed that annual applications of 22 and 45 kg N/ha for four years produced forage yields of 3,394 and 4,646 kg/ha, respectively, while single applications of the same total amounts, 90 and 179 kg N/ha produced respective yields of 3,804 and 5,392 kg/ha. In the same study, however, annual applications of phosphorus significantly increased hay yields over single applications.

In a six year study at Mandan, North Dakota, Power and

Alessi (27) concluded that total production of grass was not affected by timing of nitrogen fertilization or by the interaction of timing by rate. A given amount of nitrogen fertilizer produced essentially the same total amount of dry forage over six years whether it was applied in one year or divided into three or six equal annual applications.

On the other hand, in Colorado, McGinnies (21) obtained significantly higher average yields on annual nitrogen fertilizer applications than on biennial applications.

In a three year study in Saskatchewan on Russian wildrye Lawrence and Kilcher (19) found the greatest forage yields were obtained from stands fertilized early in the spring, while seed production was best on plots fertilized immediately following seed harvest in mid-summer. Fall applications resulted in lowest yields in both categories.

Evaluation of Responses to N-P Fertilizers

Most of the past fertility work has been done on hay yield increases (10) and although this may still be a prime consideration, it has been recognized that quality and other aspects must be considered in order to properly evaluate the response to fertilization. Thomas and Osenbrug (36) noted that crested wheatgrass and smooth bromegrass initiated growth six to ten days earlier in the spring, were marked by darker green color, and produced more vegetative growth when fertilized with nitrogen. Seed head development was increased two to three times by nitrogen fertilization.

Rogler and Lorenz (31) indicated western wheatgrass-needle and thread-blue grama sites receiving nitrogen were able to support grazing ten days earlier than the check plots. Smika, Haas and Rogler (32) found that nitrogen and nitrogen-phosphorus fertilized plots showed darker green color, more tillering and greater leafiness, and more and larger seed heads. They also noted the height of stand increased with rate of application up to and including the 67 kg N/ha rate.

Beneficial effects of nitrogen fertilization have been measured in numerous studies on range recovery and botanical composition.

Johnston et al. (15), in Alberta, Canada, found increasing amounts of nitrogen fertilizer increased basal areas of western wheatgrass, thickspike wheatgrass (*A. dasystachym*), fringed sage (*A. frigida*) and weed species, while basal areas of blue grama, needle and thread, Junegrass (*Koeleria cristata*), thread leaf sage (*Carex filifolia*) and little clubmoss (*S. densa*) decreased with increasing rates of nitrogen.

In North Dakota (27) six years of nitrogen application increased western wheatgrass and decreased blue grama and Junegrass.

Rogler and Lorenz (31) showed that there was a natural recovery of vigor and increase in western wheatgrass even without fertilization, but two years of nitrogen fertilization at 101 kg N/ha did more to improve range condition and increase yield than did six years of complete isolation from grazing.

On an overgrazed dense clay range in western South Dakota, Nichols and McMurphy (24) also found nitrogen accelerated recovery over that of the controls, but they did not believe it was economically feasible on this site.

The heaviest emphasis in the evaluation of fertility response in most studies has been on quantitative measurements. Nitrogen alone produced significant yield increases over controls in each of six years at Newell, South Dakota (36), on bromegrass and crested wheatgrass haylands when fertilized with 45 kg N/ha/yr or more. However, yield increased at a decreasing rate as nitrogen rate increased.

Kilcher (17), in a four year study in southern Saskatchewan, increased average yields of crested wheatgrass 3.7 times (from 785 to 2601 kg/ha), Russian wildrye 2.9 times (from 538 to 1390 kg/ha) and intermediate wheatgrass 1.5 times (from 1211 to 1816 kg/ha) with annual applications of 75 kg N/ha.

On needle and thread-western wheatgrass-blue grama grasslands, Rogler and Lorenz (31) doubled forage yields with annual applications of 34 kg N/ha, regardless of initial pasture condition. Generally, protein yield and concentration increased when nitrogen fertilizer was applied almost without exception.

Cosper and Thomas (8) noted increases of 1.58% and 1.78% protein over the control at 90 and 179 kg N/ha, respectively. This was on western wheatgrass and green needlegrass range. Similar results were found in other native (31, 32) and introduced (36) species.

Residual Response To Nitrogen and Phosphorus Fertilizers And Factors Affecting Its Magnitude

Mineral nitrogen applied as fertilizer may remain without substantial losses if the soil remains dry, even when broadcast. However, when drainage occurs losses will be great if too much time elapses between application and absorption by the plant (5).

Losses in leaching are dependent upon soil texture and increase with coarseness of texture. Losses due to leaching have been reported to be 99% as nitrate and less than 1% as ammonium (5). Even very moderate rainfall could cause nitrate movement on sandy loam soils (5).

Ammonium salts in an alkaline aqueous medium react with water and hydroxyl groups to produce free ammonia which escapes into the atmosphere. Thus, if ammonium fertilizers are applied to alkaline soil, free ammonia may be released to the atmosphere (37).

The greatest losses of ammonia by volatilization have been noted where the source has been broadcast. Once the ammonia has been volatilized, the soil has only a limited opportunity to readsorb it (5).

Biological reduction of the nitrate and nitrite to gaseous forms (NO, N_2O, and N_2) is accelerated as temperature and moisture levels of the soil increase (5). Broadbent and Clark (7) estimated these losses even in well aerated soils to be between ten and fifteen percent of the annual mineral nitrogen input.

Losses of phosphorus are slight in terms of leaching. Studies in Connecticut (22) during an eleven year period showed that the annual loss of phosphorus when 3372 kg P/ha were applied was only 0.1 kg P/ha through a 46 cm depth. Certainly the greatest losses of phosphorus are due to fixation (5).

Immobilization of nitrogen and phosphorus additions, particularly by microorganisms and by the roots of higher plants, must certainly be considered in determining the fate of these applied nutrients.

Despite these possible high losses claimed due to leaching, fixation, volatilization and immobilization, a considerable number of papers have shown responses over relatively long periods of time.

Mason and Miltmore (20) found yield increases over the control plot yields from one initial application of 67 kg N/ha were 68% the first year, 35% the second, 14% the third and 6% the fourth, while one initial 269 kg N/ha application increased yields 73, 53, 92 and 101% for the 1st, 2nd, 3rd and 4th years, respectively.

Smoliak (33) recorded that one initial application of 336 kg N, 75 kg P and 304 kg K/ha increased forage yields for each of eight years. Nitrogen and phosphorus contents of the grass were also significantly higher for the six year period in which these elements were studied.

Power and Alessi (27) working with western wheatgrass-blue grama range found residual responses of nitrogen were significant the second year after application at rates of 67 kg N/ha and above. Yield response increased up to 538 kg N/ha. The third, fourth and fifth years showed significant residual responses for nitrogen rates greater than 269 kg N/ha.

Black (4) recovered 66% of the nitrogen applied to crested wheatgrass and 60% of that applied to western wheatgrass-green needle-blue grama range.

In two cropping seasons, Thomas and Osenbrug (36) noted recoveries of 45 and 67 kg N/ha were 31% and 40% respectively, but by the end of five cropping seasons the recovery had increased to a total of 35% and 51%, respectively. The situation has been shown to be somewhat the contrary for phosphorus due to phosphorus fixation in the soil over a period of time.

Residual phosphorus from a 79 kg P/ha application at Newell, South Dakota (36), showed significant yield increases in only one year of six. Phosphorus recovery was 13% on wheatgrass, 8% on bromegrass and 8% on Russian wildrye (32).

Where initial levels of phosphorus were so low that the check plots showed deficiencies, yield responses to residual phosphorus were noted for two years (4).

Weed Infestation
Due To Nitrogen Fertilization

Huffine and Elder (12), in a six year study in Oklahoma, showed weeds, including annual plantain (Plantago spp.) black-eyed susan (Rudbeckin hirta), mares tail (Erigeron canadensis), and annual bromeweed (Amphiarchyric dracunculoides), produced 2 to 5 times more dry weight on pasture plots fertilized with 37 kg N/ha applications than on the control plots.

In Washington, Patterson and Youngman (26) found that without nitrogen fertilization, downy brome (Bromus tectorum) constituted 13% of the forage dry weight yield, but at 22, 45, 67 and 90 kg N/ha it increased to 47, 58, 78 and 82%, respectively. This was verified by Wilson et al. (38) who found ninety kg N/ha increased cheatgrass (Bromus spp.) infestation 400-600% (dry weight yield) while increasing the dominant bluebunch wheatgrass by 50%.

METHODS AND MATERIALS

Initial Conditions

The site was located in northwestern Faulk County in central South Dakota. The climate is semi-arid with thirty year annual precipitation and temperature averages recorded at Faulkton, eleven kilometers from the site, being respectively 44.1 cm and 7.1°C.

The soil was a Ladelle silt loam on a 0-2% north facing slope. Soil analysis was run on composite samples taken from the site before treatments were applied in order to determine the initial nutrient status of the soil. Organic matter levels were determined by the colorimetric chromic acid oxidation method (13), water soluble nitrate nitrogen by the phenoldisulfonic acid method (13), soluble P by the Bray No. 1 method (18), and exchangeable K by ammonium acetate extraction and flame emission spectrophotometry (13). Soil pH, using the glass electrode (30), and soluble salts, using the Solu Bridge salt meter (30), were run on 1:1 soil suspensions. When electrical conductivity exceeded 1.8 mmhos/cm, soluble salts and soluble sodium were determined on the saturated soil pastes (30).

Figure 1, taken just outside the site shortly after spring green-up, shows the type and condition of the vegetation as it existed on the site at the beginning of the study. The site had been moderately grazed the year previous to the study, but was clipped free of residue at the initiation of the study.

Fig. 1. Vegetation immediately outside the site as it appeared in mid-June, 1969.

Prominent species included Junegrass (*Koeleria cristata*), Kentucky bluegrass (*Poa pratensis*), little bluestem (*Andropogon scoparius*), green needlegrass (*Stipa viridula*), needle and thread (*Stipa comata*), western wheatgrass (*Agropyron smithii*), and blue grama (*Bouteloua gracilis*). There were also isolated plants of side-oats grama (*Bouteloua curtipendula*), smooth bromegrass (*Bromus inermis*), and yellow sweetclover (*Melilotus officinalis*). The only native legume present in quantity was silverleaf scurfpea (*Psoralea argophylla*). Weed species included Japanese chess (*Bromus japonicus*) as well as isolated plants of fringed sage (*Artemisia frigida*) and Flodman's thistle (*Circium flodmanii*).

Application of Treatments

Treatments included two rates of phosphorus (0 and 20 kg P/ha) applied as concentrated superphosphate, seven rates of nitrogen (0, 34, 67, 135, 269, 538, and 1076 kg N/ha) applied as ammonium nitrate, and two dates of nitrogen application (April 17, 1969 and June 9, 1969). All phosphorus was applied on April 17, 1969.

The treatments were laid out in a randomized block design with split-split plots. All treatments were replicated four times, giving a total of 112 plots with dimensions of 2.1 x 6.4 meters.

After the initial applications of nitrogen and phosphorus, no other applications were made, and any responses beyond the first growing season were strictly due to residual fertilizer.

All fertilizer was broadcast onto the surface. No plot was ever sprayed to control weeds at any time during the study.

Harvest of Plots

Those plots receiving the "early" application of nitrogen (April 17, 1969) were cut on June 30, 1969 and a second cut was taken September 8, 1969. The plots receiving the "late" nitrogen application (June 9, 1969) were cut only once, on August 14, 1969. The second year, both "early" and "late" plots were cut only once (the "early" plots on June 24, 1970 and the "late" plots on August 7, 1970). Notes were taken prior to cutting whenever possible.

All plots were cut with a rotary flail mounted to a Model 112 John Deere garden tractor. The flail, manufactured by Haban of Racine, Wisconsin, was adapted with a collection cage. The main drive and knives were reversed so that the forage was thrown up and blown into the collection cage. The flail is pictured in the Appendix.

Immediately after cutting, the forage was weighed on a milk scale and a moisture sample taken and weighed on a single beam balance. These samples were air dried and then later returned to Brookings for oven drying and re-weighing.

Plant Analysis

After oven drying, the plant samples were ground and bottled for storage until analysis.

In both years all samples were analyzed for crude protein using the macro-Kjeldahl method with Kel-Pac No. 2 (10 g K_2SO_4 + 0.30 g $CuSO_4$). A digest was prepared using a procedure outlined by Allen (2) in which one gram of plant material was digested in 10 ml of nitric acid and heated until reduced to 1 ml, cooled, further digested with 2.5 ml of perchloric acid, filtered and diluted to 50 ml. This resulted in a final dilution of 1:50, and this was then used in the determination of the individual mineral element constituents, except for plant nitrates.

In 1969, aliquots of these digests were analyzed for total phosphorus using Barton's (3) solution and a Coleman Model 6A spectrophotometer. Total potassium was determined directly by reading a diluted aliquot on the Perkin-Elmer Model No. 146 flame photometer.

Water soluble plant nitrates were run using a procedure outlined by Johnson and Ulrich (14).

In addition to the analysis run in 1969, the 1970 samples were also analyzed for calcium and magnesium using the Jarell-Ash atomic absorption spectrophotometer, Model No. 82-516 and a modification of the procedure outlined by David (9). Also, total sulfur was determined by the use of a turbidimetric procedure outlined by Blancher et al. (6). Each of these procedures required the use of aliquots of the HNO_3-$HClO_4$ digestion solution.

The analysis of variance was made with the aid of the South Dakota State University computer center facilities and with the assistance of the Experiment Station Statistician, Dr. Lee Tucker. Differences between nitrogen rates were determined by using orthogonal comparisons according to Steel and Torrie (35).

RESULTS AND DISCUSSION

Climatic Conditions

Monthly precipitation received during the 1969 and 1970 study as compared to the long term precipitation normals indicates that annual and seasonal precipitation were subnormal (Table 1). Note the high rainfall in June and July of 1969 as compared to 1970 when considerably less moisture was received during these two critical months. The March through August precipitation is also reported because it is probably a better measure of growing season precipitation than the April through September precipitation.

Soil Analysis

Soil analysis data as displayed in Table 2 show soil fertility levels within the 122 cm profile. Organic matter was rated in the "medium" range according to the South Dakota State University soil testing laboratory. Nitrate-nitrogen was considered to be almost negligible. Phosphorus levels were rated "very low" throughout the 122 cm profile. Potassium was rated "high" in the 15.2 cm surface layer and "medium" throughout the remainder of the profile. Soluble salts and soluble sodium were quite high in the lower part of the profile. However, these levels were not considered critical and are common in this region.

Table 1. Monthly precipitation* and temperature data for the Pasture Research Center for the duration of the study and the long time normals.

	Average monthly precipitation, 1931-1960 cm	1969 Monthly precipitation, cm	1969 Deviation from the normal, cm	1970 Monthly precipitation, cm	1970 Deviation from the normal, cm	Average monthly temperatures, 1931-1960 °C
January	1.19	3.25	+2.06	0.15	-1.04	-10.4
February	1.19	5.26	+4.06	0.25	-0.94	- 8.3
March	2.26	1.02	-1.24	1.12	-1.14	- 1.6
April	4.72	1.90	-2.82	7.24	+2.51	7.4
May	6.55	3.15	-3.40	3.63	-2.92	14.1
June	9.01	9.78	+0.76	7.54	-1.47	19.1
July	5.41	9.17	+3.76	3.61	-1.80	23.2
August	5.23	4.16	-1.07	1.88	-3.35	22.1
September	3.35	0.86	-2.49	4.22	+0.86	16.4
October	2.77	0.38	-2.39	2.11	-0.66	9.6
November	1.50	0.71	-0.79	3.22	+1.73	0.1
December	0.89	2.03	+1.14	1.27	+0.38	- 6.4
Total	44.09	41.68	-2.41	36.24	-7.85	
Apr.-Sept.	34.29	29.03	-5.26	28.12	-6.17	
Mar.-Aug.	31.95	29.18	-2.77	25.02	-6.93	

* The long term precipitation and temperature normals were taken at Faulkton, S. D. while the 1969 and 1970 data were recorded at the Pasture Research Center at Norbeck, about twenty six kilometers north-west of Faulkton, S. D.

Table 2. Soil test data* of the native grass site before initial treatments.

Sample depth, cm	Organic matter, %	Nitrate nitrogen, ppm NO_3-N	Bray P-1 phosphorus, kg P/ha	Exchangeable potassium, kg K/ha	pH 1:1dil.	Soluble salts, mmho/cm paste	Soluble salts, mmho/cm 1:1dil.	Soluble sodium, meq Na/l
0- 15.2	2.6	0.6	5.6	308.3	7.4		0.59	
15.2- 30.5	1.6	0.1	3.4	208.5	7.9		0.40	
30.5- 45.7	1.0	0.6	1.1	227.6	8.1		0.49	
45.7- 61.0	0.9	0.3	1.1	208.5	8.3		0.95	
61.0- 76.2	0.6	0.2	1.1	213.0	8.2	6.5		30.5
76.2- 91.4	0.4	0.4	3.4	234.3	8.4	6.5		30.5
91.4-106.7	0.6	0.8	5.6	227.6	8.4	7.5		75.7
106.7-121.9	0.4	0.9	6.7	234.3	8.4	7.5		75.7

*These data are from the analysis of composite samples taken throughout the site located on NE 1/4 Sec 14 T120N R70W of 5th P.M.

Visual Evaluation and Yield Data

Notes were taken at the site periodically during both growing seasons in an attempt to describe the effects of the treatments as they affected the plant community. Most of the observations were made just prior to the harvests, while the remainder were taken on spring green-up and regrowth.

Observations with the corresponding harvest data for each cutting are reported first. Then in a separate section following the observation and individual yield results; I have made an over-all evaluation of the treatments and their effects on forage yields. Then in later sections I have discussed the effects of nitrogen and phosphorus fertilization on other aspects of forage quality.

It must be remembered that the data reported were for all forage, and no attempt was made to remove weeds or forbs from the grass.

The "early" application of nitrogen - 1969

Observation date 1

The first observation made of the site was on May 15, 1969, about one month after the "early" application of nitrogen and phosphorus fertilizer. Fig. 2 shows the earlier green-up of the nitrogen fertilized plots.

Fig. 2 Effect of nitrogen fertilizer on spring green-up of the native grassland. This photograph was taken May 15, 1969, one month after the phosphorus and "early" nitrogen application.

Observation date 2

At the time of the "late" application of nitrogen on the site (June 9, 1969), it was possible to see the response to nitrogen fertilization on the "early" application plots which had been fertilized on April 17. Fig. 3 shows what seemed to be a phosphorus response at least in the seed production of the bluegrass. Note the nitrogen response of the 135 kg N/ha rate immediately behind the signs and the 1076 kg N/ha rate in the immediate foreground as compared to the control plot in the middle.

Fig. 3 Effect of phosphorus on seed head production of Kentucky bluegrass. Plots to the left of the flags received 20 kg P/ha (40 lbs P_2O_5/ acre), those to the right received none.

On two of the replicates, the 1076 kg N/ha rate was burned and salted quite severely, but existing vegetation seemed vigorous and healthy (Fig. 4). Note the plot to the right of the 1076 kg N/ha rate which received 34 kg N/ha showed little growth response.

Nitrogen fertilized plots in general were darker green and taller with each increasing rate up to and including the 269 kg N/ha rate. Already differences in density of stand due to tillering were noted. Nitrogen increased the number of seed heads on Kentucky bluegrass, especially.

Fig. 4 Salt effect on native grasses at 1076 kg N/ha (960 lbs N/acre).

Observation date 3

Fig. 5, taken mid-June shows increased growth from applied nitrogen eight weeks after the application date of April 17. The prominent grass at this time was Kentucky bluegrass.

Fig. 5 Nitrogen response at two months after the "early" application of nitrogen.

Observation date 4

On June 30, 1969, just before the first cutting of the "early" application plots, notes were taken on these plots and are compiled in Table 3. At this time, even without the aid of a diagram, one could easily rank these treatments one to seven by observing the increased density, height of stand, number of seed stalks and greenness of the grass with each increased rate of nitrogen.

Although not mentioned in the notes, the growth habit of western wheatgrass became less erect and the leaves spread out more horizontally with increasing nitrogen rates.

June 30, 1969 - First harvest of plots with the "early" application of nitrogen.

Although observation seemed to indicate that each rate of nitrogen increased height and stand density up to and including the 538 kg N/ha rate, the yield data (Fig. 6) do not substantiate the observations completely. Peak production of dry forage was at the 67 kg N/ha rate where no phosphorus was applied, and at 135 kg N/ha where 20 kg P/ha were applied.

Observation date 5

At the time of the first cut of the "late" application (August 7, 1969), notes were taken on the regrowth of the "early" application plots and these are compiled in Table 4.

Fig. 7 illustrates the regrowth as affected by nitrogen four weeks after the first cutting. Most of the regrowth was warm season species, especially little bluestem, but also some late cool season species including green needlegrass and western wheatgrass were present in quantity.

Table 3. Compilation of observations from four replications made on June 30, 1969 on native grass plots fertilized "early" (April 14, 1969).

Fertilizer Treatment	Field Notes
Control	Plots appeared yellow-green and overall stands were thin. Bluegrass seldom had seed stalks and when present very little foliage was associated with them. Western wheatgrass, when present, was short (10-15 cm or less) with never more than one shoot arising from any single plant. This western wheatgrass was very erect in growth habit with leaves pointed up almost parallel to the stalk. Overall, the control plots lacked vigor.
34 kg N/ha	There was a slightly darker green color noted on these plots than on the controls. There were slightly more bluegrass seed stalks. Western wheatgrass showed the greatest response with plants being taller, leafier and somewhat more tillered making them more conspicuous than in the control. Overall, there was a slight increase in vigor.
67 kg N/ha	Color of these plots was obviously darker green than the control or the 34 kg N/ha rate. Little bluestem, where present, was denser than the control. Bluegrass seed stalks were present in greater quantity than in the two previous treatments. Western wheatgrass was taller and more tillered.
135 kg N/ha	Color was darker green than the 67 kg N/ha rate. Bluegrass showed great increase in seed production and number of seed stalks. Needle and thread showed a considerable number of seed stalks whereas very few were noted at lighter nitrogen rates. Little bluestem displayed health and vigor. Western wheatgrass was more dominant due to increased tillering. Many western wheatgrass plants had three mainstems arising from one plant. Overall it was about 25 cm tall where present. Also, western wheatgrass displayed more seed stalks than it had at lighter nitrogen rates.
269 kg N/ha	These were possibly the more vigorous plots on the site. Little bluestem was 7-12 cm tall whereas in the control it was about 3 cm tall. Bluegrass displayed more seedheads that were taller and heavier than those at lighter rates. Western wheatgrass was 22-30 cm tall and tillered very well. Overall, stand was taller and greener with increased leafiness and vigor. Western wheatgrass was bluer.

Table 3. (Continued)

Fertilizer Treatment	Field Notes
538 kg N/ha	Two of the four replications showed burning and some salt effects on this treatment. However, all existing foliage was dark green except for little bluestem which tended to be more red-purple. Seed head production was great on bluegrass, needle and thread and smooth bromegrass when present, but the same was true for Japanese chess. Silverleaf scurfpea was twice as tall as it was on the control. Western wheatgrass was tall and seemed to be able to tolerate the salt effect even in plots where considerable damage was noted in other grasses.
1076 kg N/ha	Salt injury and burning were even more evident here than at the 538 kg N/ha rate, but existing vegetation was dark green and appeared healthy. Smooth bromegrass and western wheatgrass tolerated the rate well without burning, while the little bluestem seemed to be thinned out. Tremendous leafiness was noted. Bluegrass had leaves that measured 30 cm in length and bromegrass displayed extremely wide leaves when present.
20 kg P/ha	No clear cut phosphorus response was noted. However, one replication seemed to show a slight response in seed stalk production of bluegrass.

Fig. 6. First cut forage yield in 1969 as affected by applied phosphorus and various nitrogen rates when applied "early".

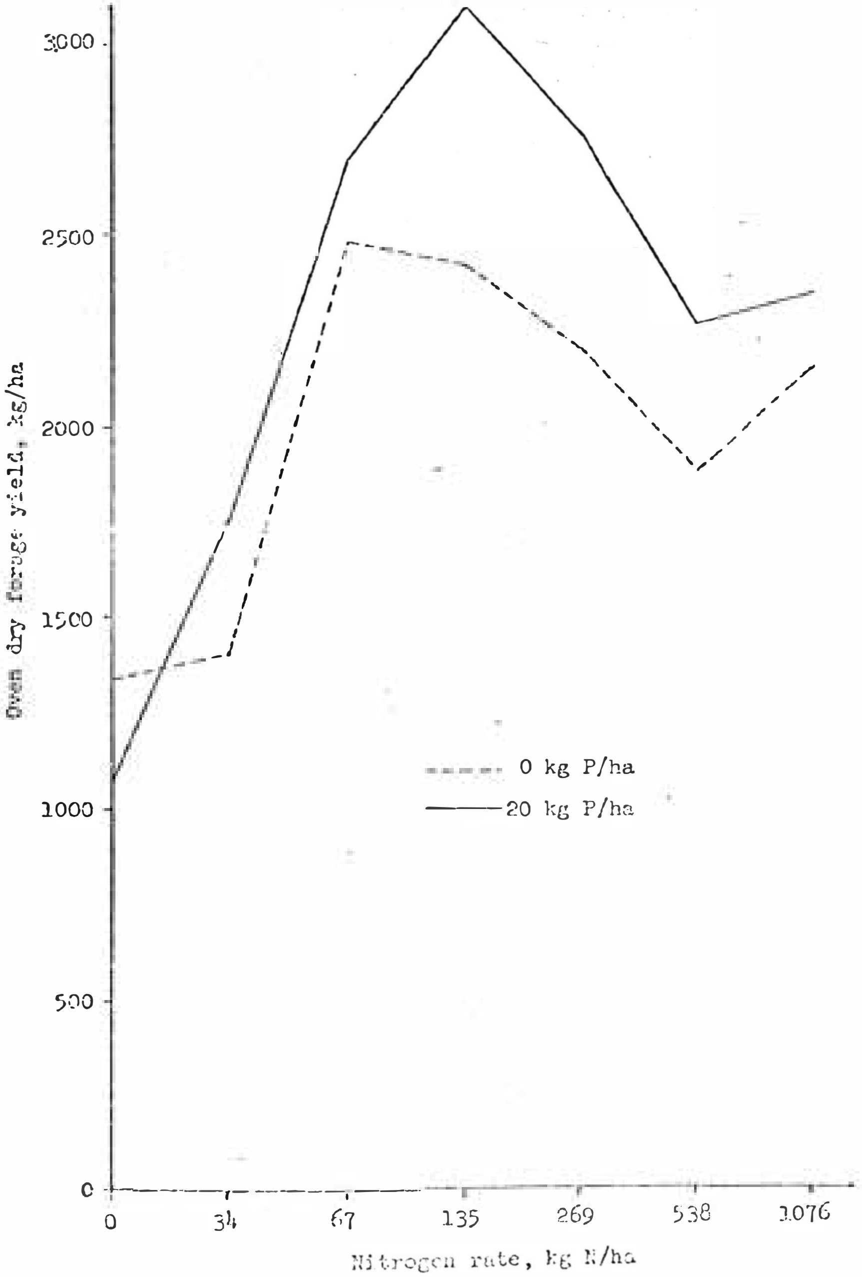


Table 4. Compilation of observations made on August 7, 1969 on the regrowth of plots fertilized "early" (April 17, 1969) and cut on June 30, 1969.

Fertilizer Treatment	Field Notes
Control	Regrowth after the first harvest was extremely slow. The stand was light colored and thin. A few scattered stalks of western wheatgrass were present, but lacked vigor. A few plants of little bluestem were heading out.
34 kg N/ha	These plots looked very much like the control and regrowth was very slow.
67 kg N/ha	Although the color was slightly darker than the control, regrowth was more rapid with little bluestem, blue grama and green needlegrass heading out. Overall stand was taller than the control.
135 kg N/ha	Darker green color and denser foliage was noted. Little bluestem displayed a considerable increase in seed stalk production as compared to lower rates. Western wheatgrass was well tillered and two to three times as tall as the bluestem foliage.
269 kg N/ha	These plots showed a tremendous regrowth of dark green foliage. Little bluestem was well headed out. Western wheatgrass seemed more abundant than in the control plots. Weedly species were invading these plots, especially Flodman's thistle.
538 kg N/ha	Even greater regrowth was noted than on the 269 kg N/ha plots, including regrowth by Flodman's thistle, fringed sage and Japanese chess. Grasses were lodging and tangling. Plots were dark green.
1076 kg N/ha	Regrowth was very rapid. The little bluestem, sideoats grama and green needlegrass were headed out and displayed heavy seed heads. Western wheatgrass had increased considerably, but even greater increases were made by Flodman's thistle and other weeds.

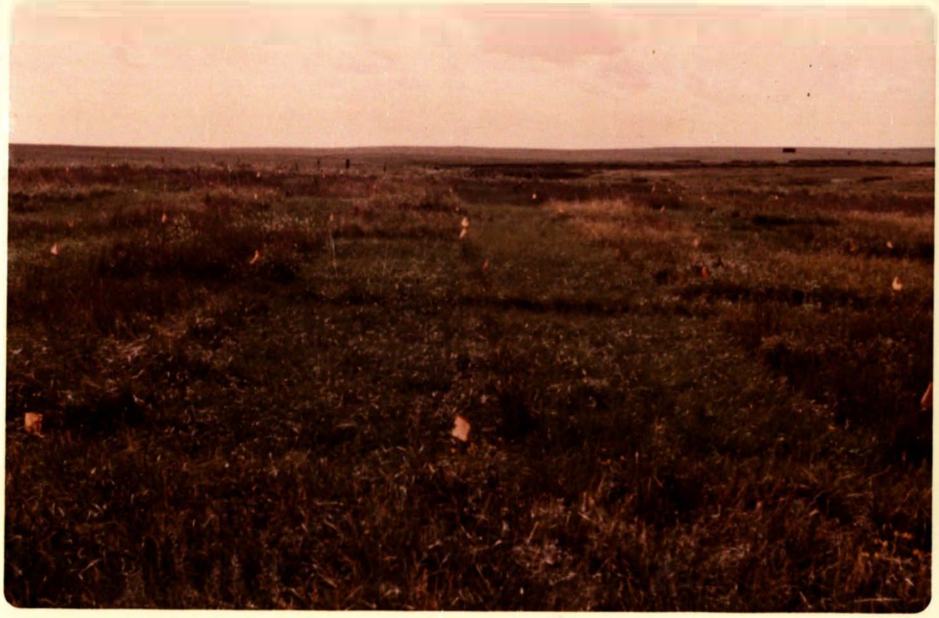


Fig. 7 Regrowth on "early" nitrogen fertilized plots (center) four weeks after harvest. The plots to the right and left of these plots are their counterparts that received the "late" application of nitrogen and were not yet cut at this date. The plots on the right received 135 kg N/ha, those on the left 1076 kg N/ha.

At the time the notes were taken, scattered plants of little bluestem, blue grama, and green needlegrass were heading out in spite of being clipped earlier (Table 4).

At this time, the 34 kg N/ha rate was similar to the control and the 67 kg N/ha was the lightest rate to show the effects of the added nitrogen (Table 4).

September 8, 1969 - Second cut (regrowth harvest) of plots with the "early" application of nitrogen.

There is a considerable change in the shape of the graph in the second cutting (Fig. 8) as compared to the first (Fig. 6) in that the peak yields are recorded at a higher rate, 269 kg N/ha, regardless of phosphorus treatment.

Statistical analysis of the "early" application harvests in 1969

Analysis of variance indicated there were no significant differences between the two cuttings with respect to forage yield, nor did addition of phosphorus account for any significant difference in forage yield. However, yields shown in Fig. 9 tended to indicate that phosphorus increased forage yields somewhat at the higher rates of nitrogen.

Orthogonal comparisons were made between levels of nitrogen, comparing each rate with all higher rates combined. These show that the combined nitrogen rates produced highly significant (.01 level) increases in yield over the control and that the yield at 34 kg N/ha showed yield increases that were highly significant when compared to the higher rates. There were no significant differences beyond the 67 kg N/ha rate.

The 67 kg N/ha rate produced the greatest amount of forage per kg of applied nitrogen followed by the 34 kg N/ha,

Fig. 8. Second cut forage yield in 1969 as affected by applied phosphorus and various nitrogen rates when applied "early".

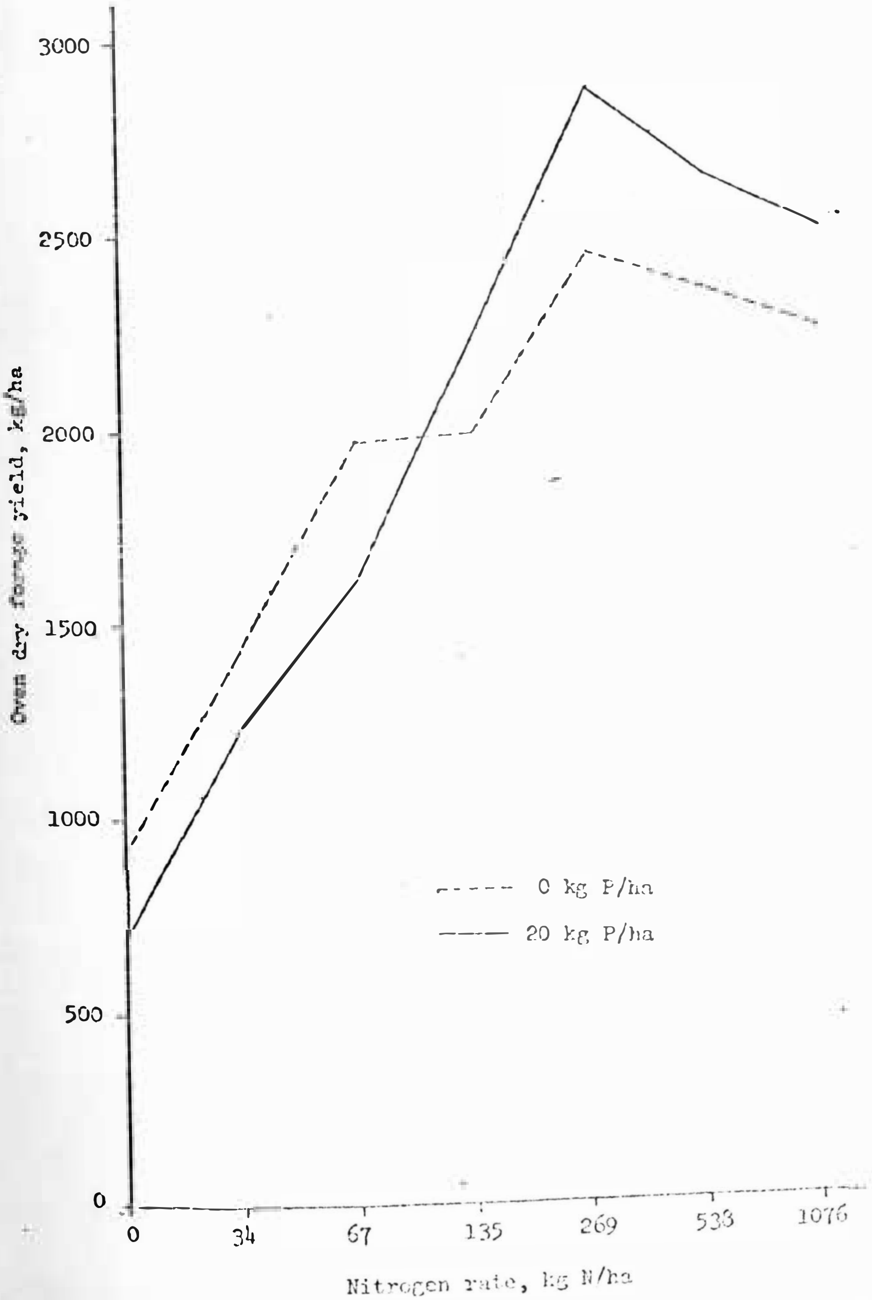
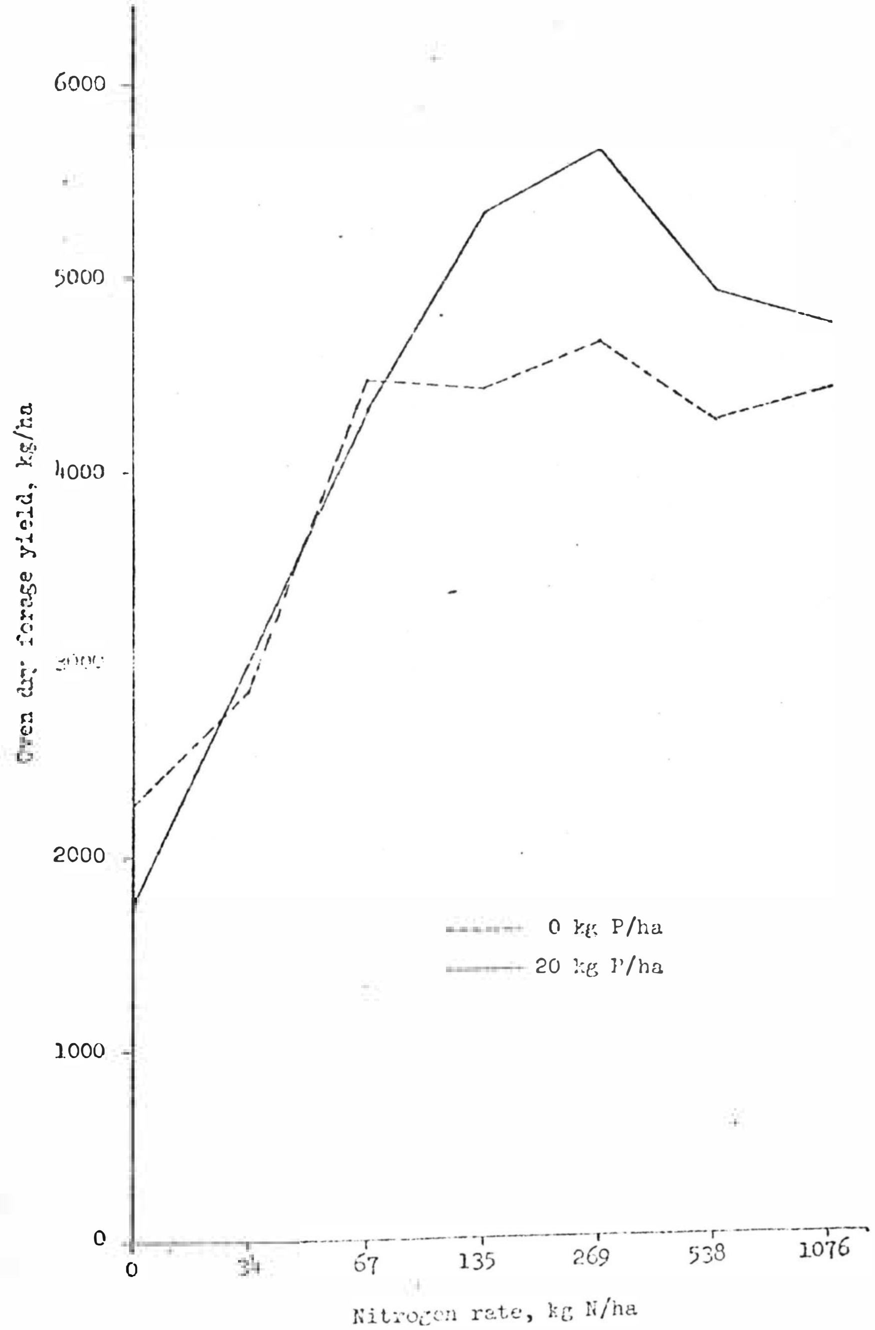


Fig. 9. Total forage yield of two cuttings in 1969 as affected by applied phosphorus and various nitrogen rates when applied "early".



135 kg N/ha, 269 kg N/ha, 538 kg N/ha, and 1076 kg N/ha, respectively, with or without applied phosphorus.

The interactions of phosphorus with cuttings, nitrogen with cuttings, and nitrogen with phosphorus were all statistically nonsignificant.

The "late" application of nitrogen - 1969

Observation date 1

The first observation on these plots was made on June 30, 1969 at the time of the first cutting of the "early" application plots. These observations are compiled and presented in Table 5. They indicate that three weeks after application of nitrogen, increased growth and darker green color could be noted at rates of 67 kg N/ha and above.

Observation date 2

The next observation was made on August 7, 1969 just prior to the harvest of these plots. These are compiled in Table 6. According to these notes, the weed problem was considerably more acute than it had been in the "early" application plots. These stands were composed primarily of little bluestem which was completely headed. Fig. 7 shows the condition of the stand and its maturity a week before the harvest.

Table 5. Compilation of observations from four replications made on June 30, 1969 on native grass plots fertilized "late" (June 9, 1969).

Fertilizer Treatment	Field Notes
Control	These plots were yellow-green in color and overall stands were thin. There were a few seed stalks of bluegrass, but very little foliage associated with them. These plots simply lacked vigor.
35 kg N/ha	There was no difference between these plots and the controls.
67 kg N/ha	A darker green color was just becoming obvious at this rate.
135 kg N/ha	These plots showed increased growth and leafiness and darker color than the control.
269 kg N/ha	These plots were darker green, taller and denser in stand than the lighter rates. Western wheatgrass was already becoming more prominent in the stand.
538 kg N/ha	One replicate was starting to show salt injury. Plots were darker green than those at lighter rates and the western wheatgrass was taller and more vigorous.
1076 kg N/ha	Color was dark green. Salt injury was beginning to become evident.

Table 6. Compilation of observations from four replications made on August 7, 1969 on native grass plots fertilized "late" (June 9, 1969).

Fertilizer Treatment	Field Notes
Control	Stands were yellow-green in color with darker blotches occasionally, possibly indicating deposits of cattle urine at some time in the past. Stand was generally thin and about 7-10 cm tall. There was some little bluestem heading out, but fewer than on the fertilized plots. A few weeds and a few plants of western wheatgrass that lacked vigor were present.
34 kg N/ha	These plots looked very much like the controls in every respect including color.
67 kg N/ha	A slightly darker green color was noted in these plots. More weeds were present than in the controls. More seed production by the little bluestem was noted.
135 kg N/ha	These plots were quite weedy with some of these weeds being Flodman's thistle. Little bluestem showed a large amount of heading when compared to lighter rates.
269 kg N/ha	Here the stand was thicker, darker green, and taller than on the lighter rates, but weeds, including Flodman's thistle were a considerable problem. Much of the foliage was lodged and tangled.
538 kg N/ha	Little bluestem was headed out completely and showed tremendous seed head production. The plots were lodged and tangled to form about a 15-20 cm mat with seed stalks rising above this to about 35 cm. Weeds posed a significant problem with Flodman's thistle, yellow sweetclover, gumweed and fringed sage making vigorous growth. Color of the plots was dark green. No salt injury was evident.
1076 kg N/ha	These plots showed no salt injury or even burning. Growth was thick, heavy and dark green. Once again weeds were a problem, especially Flodman's thistle.

August 7, 1969 - Harvest of plots with the "late" application of nitrogen

Fig. 10 indicates that forage yields were greatest at the 538 kg N/ha and 269 kg N/ha rates at 0 and 20 kg P/ha, respectively. As was the case with the "early" application, the detrimental effects can be seen at the higher rates of nitrogen. Note that yields do not level off at any point as they did in earlier graphs, but climb steadily to their peaks and rapidly drop off.

The "early" application of nitrogen - 1970

Observation date 6

These plots were observed on June 22, 1970 at the time of the only cutting made during the second growing season. There were no visible differences between the "early" and "late" application plots; therefore, observations on plots of both application dates were made collectively and are presented in Table 7.

The notes certainly seem to emphasize to a greater degree the problem of weed infestation than they had in 1969 (Table 7). This was especially true at the higher rates of nitrogen.

Western wheatgrass seemed to be less vigorous at the 67 kg N/ha than it had been in 1969, but there seemed to be more present than in the control or 34 kg N/ha rate plots (Table 7).

Fig. 10. Forage yield in 1969 as affected by applied phosphorus and various nitrogen rates when applied "late".

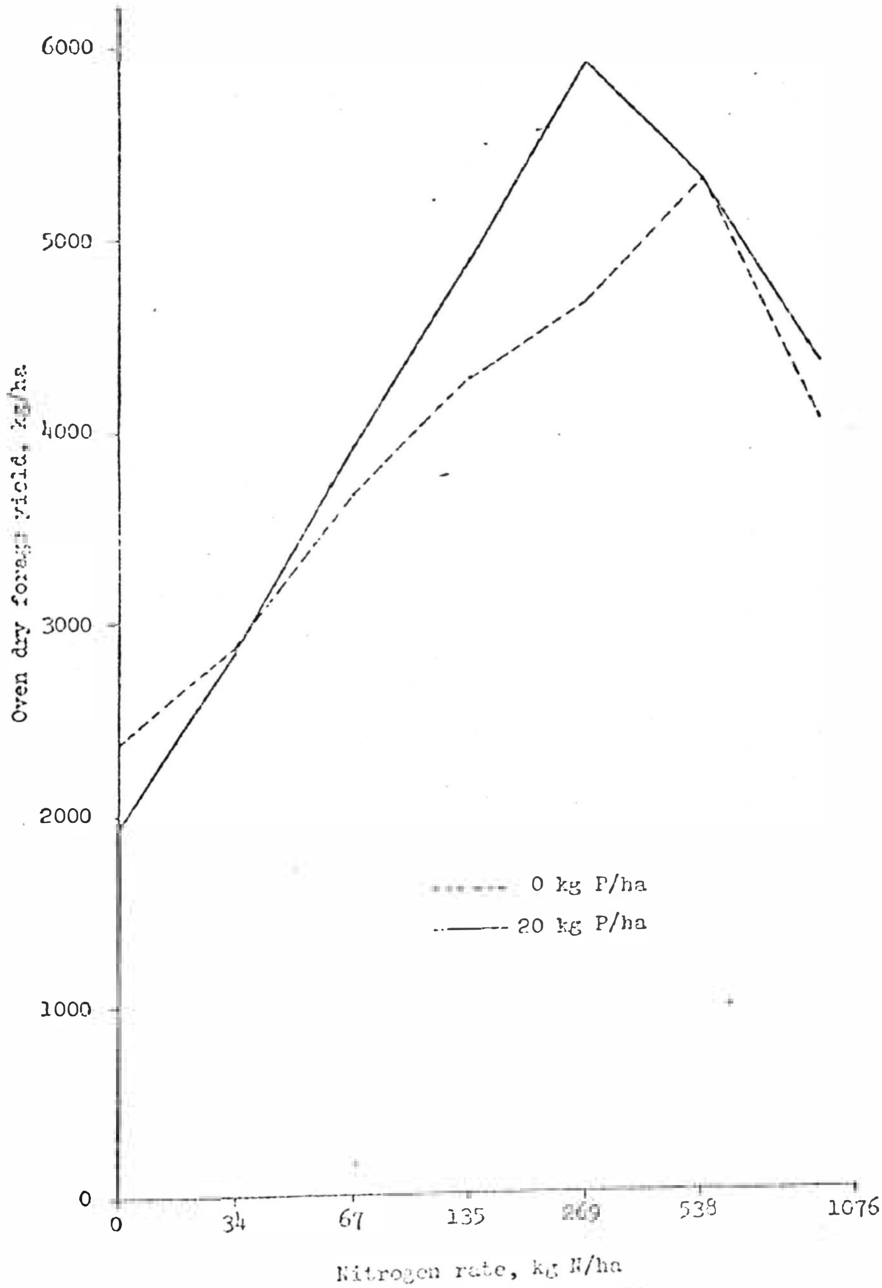


Table 7. Compilation of observations from four replications made on June 22, 1970 on native grass plots fertilized "early" (April 17, 1969) and "late" (June 9, 1969), collectively.

Fertilizer Treatment	Field Notes
Control	Overall, the grass stand was about 5-8 cm tall with a few isolated plants of western wheatgrass reaching 15 cm. Very little forage was present due to the prevailing moisture conditions. Plots were light yellow-green with almost no seed stalks present on any grass.
34 kg N/ha	These plots seemed very little different than the control plots except that there seemed to be a few more seed stalks of bluegrass.
67 kg N/ha	Growth was greater than that of the control. A good deal of western wheatgrass was coming in, but it seemed erect and not especially vigorous. A few seed stalks were present, and the color of the plots was light green. A few broadleaved weeds and some Flodman's thistle were present.
135 kg N/ha	These plots showed taller and thicker stands than the 67 kg N/ha rate. Bluegrass and the Stipas showed more seed stalks. Some Flodman's thistle was present as well as other broadleaved weeds.
269 kg N/ha	These plots were the first to show the dark green color attributable to the residual nitrogen. There were a considerable number of seed stalks of bluegrass, needle and thread, green needlegrass and smooth bromegrass. Western wheatgrass has shown a considerable increase in these plots. Flodman's thistle, Japanese chess and a variety of other broadleaved weeds have increased considerably over the lighter rates.
538 kg N/ha	Plots were very dark green in color with western wheatgrass, needle and thread, green needlegrass and where present, smooth bromegrass becoming very dominant over other species. Flodman's thistle invasion was very severe in three of the four replications. Broadleaved weeds were numerous and Japanese chess had greatly increased with individual plants and seed heads being very large. Seed stalks were numerous on bluegrass, needle and thread and smooth bromegrass.
1076 kg N/ha	Plots were dark green and stands were predominantly western wheatgrass, green needlegrass, and needle and thread with some bromegrass and bluegrass present. Weeds had

Table 7. (Continued)

Fertilizer Treatment	Field Notes
	greatly increased, especially Flodman's thistle and Japanese chess. There was considerable seed production of the grasses mentioned except for western wheatgrass which had not headed out. Japanese chess had very large seed heads.

June 22, 1970 - Harvest of plots with the "early" application of nitrogen.

As no more nitrogen had been applied since the original application on April 17, 1969, all yield increases noted in Fig. 11 are due to residual nitrogen.

The moisture situation at the time of this cutting as displayed in Table 1, was considerably less favorable than it had been at the time of the first cutting in 1969. This is verified by low yield data displayed in Fig. 11. The greatest decrease in yield occurred on the control plot where the 1970 yield was 679 kg/ha as compared to 1341 kg/ha and 924 kg/ha for the first and second cuts in 1969, respectively (Figs. 6 and 8). However, the 1076 kg N/ha rate showed recovery from the salt injury and burning effects noted in 1969, and produced greater yields in 1970 than for either cut in 1969.

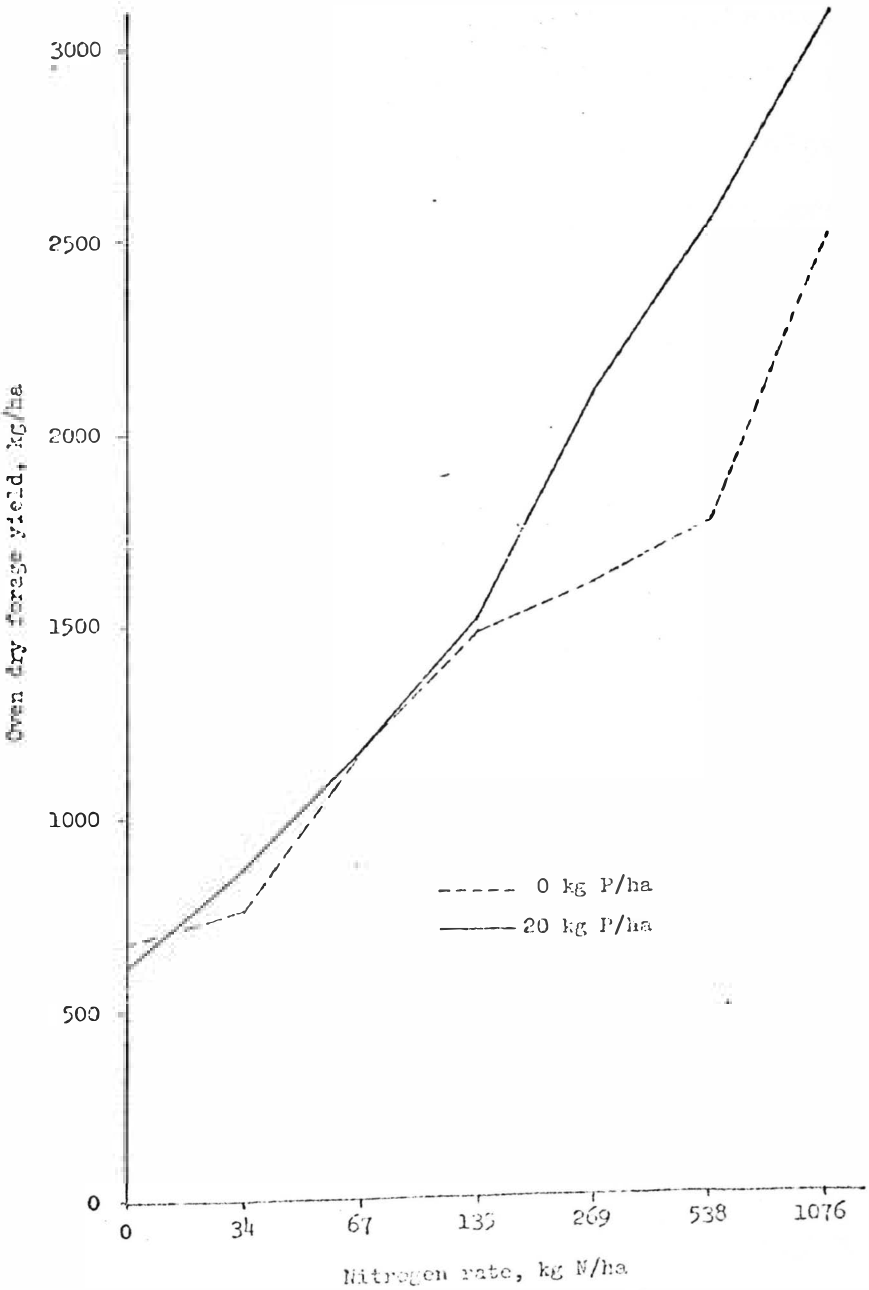
Forage yield tended to increase with increasing rates of nitrogen (Fig. 11). The addition of phosphorus appeared to decrease yields when no nitrogen was applied.

It must be mentioned that weeds were not removed from the forage and therefore some of the reported forage yields include weeds.

Observation date 7

Observations were made on the regrowth of plots fertilized "early" at the time of harvest of the "late" fertilized

Fig. 11. Forage yield in 1970 as affected by residual phosphorus and residual nitrogen at various rates when applied "early".



plots on August 7, 1970.

Although it had been almost seven weeks since these plots had been cut, all rates through the 135 kg N/ha rate showed no regrowth due to the lack of moisture during July (Table 1). The 269 kg N/ha rate showed some recovery, especially where smooth bromegrass and Flodman's thistle were present, but little bluestem showed very slow recovery. The 538 and 1076 kg N/ha rates showed slightly greater recovery, but again, the plants making the greatest recoveries were Flodman's thistle and smooth bromegrass.

The "late" application of nitrogen - 1970

Observation date 3

Observations were made June 22, 1970. The primary vegetation was cool season species and the lightest rate to show any growth response was the 67 kg N/ha rate.

Observation date 4

Observations were made on these plots again at the time of cutting on August 7, 1970. These are compiled and presented in Table 8. By this time little bluestem made up the bulk of the forage stand, but western wheatgrass was present in greater quantity with increasing nitrogen rates. All fertilized plots seemed to show greater weed infestation than the control and Flodman's thistle was especially a problem at the rate of 269 kg N/ha and above.

Table 8. Compilation of observations from four replications made on August 7, 1970 on native grass plots fertilized "late" (June 9, 1969).

Fertilizer Treatment	Field Notes
Control	The stand was short, thin and light colored and consisting primarily of little bluestem with some green needlegrass, needle and thread and western wheatgrass present. However, western wheatgrass plants were small and erect showing little vigor.
34 kg N/ha	These plots looked very much like the control, but seemed to be weedier.
67 kg N/ha	Plots were light colored. Western wheatgrass present lacked vigor.
135 kg N/ha	These plots were slightly darker green than the control or the 67 kg N/ha rates. Little bluestem made the bulk of the stand. Western wheatgrass was present in greater quantity than it was in the control. A few weeds were present.
269 kg N/ha	Stand was darker green and taller than it was at lighter rates. Western wheatgrass was abundant and showed great vigor as did the Stipas. Flodman's thistle and other broadleaved weeds had severely invaded these plots.
538 kg N/ha	Plots were dark green. Little bluestem was taller and thicker than it had been at lighter rates. There was a considerable number of weedy plants with Flodman's thistle being one of the major invaders.
1076 kg N/ha	Flodman's thistle and Japanese chess as well as a variety of broadleaved weeds had infested these plots. Overall color was dark green with a vigorous stand of little bluestem, western wheatgrass and Stipas mixed with the weeds.

August 7, 1970 - Harvest of plots with the "late" application of nitrogen

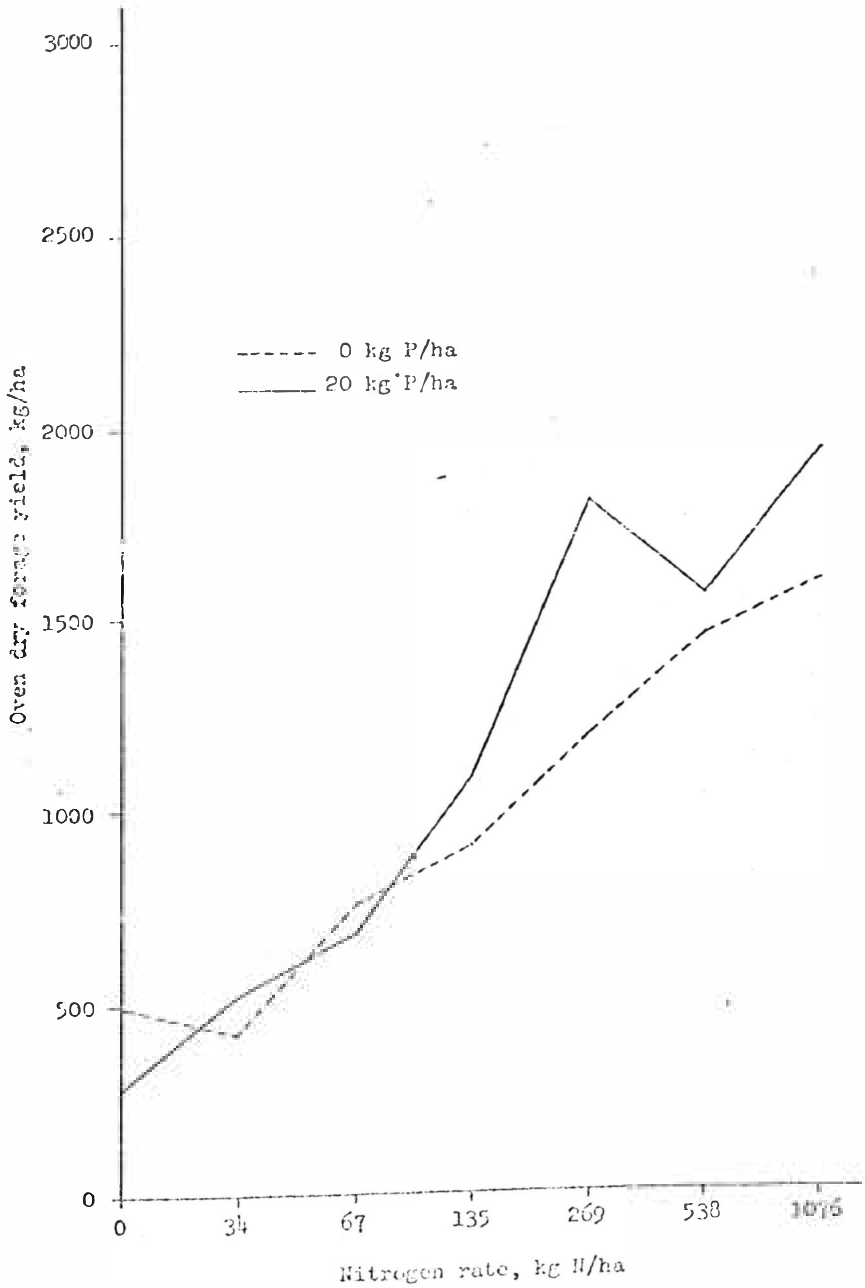
As no additional fertilizer was applied since the original June 9, 1969 application, all yield responses in Fig. 12 are due to residual nitrogen and phosphorus. The generally low yields are an indication of the moisture stress of the 1970 growing season.

Note that the yields of the "late" application (Fig. 12) are all less than the corresponding yields of the "early" application plots (Fig. 11) which were cut six weeks earlier, even though the observations made on June 22 (Table 7) indicate these plots looked very much alike at this date. This is probably because the cool season grasses on the "late" plots reached maturity and deteriorated, while the warm season grasses that normally increase growth at this time were under drought stress and could not increase.

Statistical analysis of forage yield on the entire experiment

To analyze the yield data statistically for the two year period it was necessary to consider the yields obtained each year for each application date as an individual harvest. Therefore, in the analysis of variance, the two 1969 harvests from the "early" application of nitrogen treatment were totalled and this total was considered as one harvest (1969 "early" application). The other harvests were designated the 1969 "late", 1970 "early", and 1970 "late" application of nitrogen.

Fig. 12. Forage yield in 1970 as affected by residual phosphorus and residual nitrogen at various rates when applied "late".



The analysis of variance for the two years of forage yields indicates a highly significant (.01 level) difference between years. This can be explained quite easily by comparing the monthly moisture data shown in Table 1. Moisture conditions were considerably less favorable during the 1970 growing season than during the 1969 growing season, and are especially reflected by the reduced yields of the control plots in the second year (Tables 9 and 10). The "early" application control yield dropped from 2265 kg forage/ha in 1969 to 679 kg forage/ha in 1970 and the "late" application control dropped in yield from 2377 kg forage/ha in 1969 to 490 kg forage/ha in 1970, 70% and 79% yield reductions, respectively.

The analysis of variance indicated that nitrogen produced highly significant (.01 level) increases in forage production. Two separate orthogonal comparisons for nitrogen rates were made in order to determine which nitrogen levels produced significant increases in forage yield. These comparisons are presented in Table 11. Comparison I indicates that significant yield increases at the 0.1 level were noted between the control and the 34 kg N/ha rate and between the 67 kg N/ha rate and the 135 kg N/ha rate. The 269 and 538 kg N/ha rates produced yields that were not significantly different. Comparison II showed that the 67 kg N/ha treatment produced highly significant yield increases over the 34 kg N/ha rate, while the 269 kg N/ha rate significantly increased yields over the 135 kg N/ha rate at the 0.1 level.

Table 9. Forage yield and efficiency of applied nitrogen on native grass over a two year period with all nitrogen applied "early" (April 17, 1969).

Nitrogen rate, kg N/ha	Phosphorus rate, kg P/ha	Forage yield 1969 kg/ha	Forage yield 1970 kg/ha	Total forage yield kg/ha	Total increase over control kg/ha	Efficiency of applied nitrogen, kg forage/kg N
0	0	2265	679	2944		
34	0	2840	754	3594	650	19.1
67	0	4465	1176	5641	2697	40.2
135	0	4414	1484	5898	2954	21.9
269	0	4661	1612	6273	3329	12.4
538	0	4258	1766	6024	3080	5.7
1076	0	4420	2524	6944	4000	2.3
0	20	1774	695	2389		
34	20	2983	869	3852	1463	43.0
67	20	4312	1177	5489	3100	46.3
135	20	5335	1512	6847	4458	33.0
269	20	5647	2113	7760	5371	20.0
538	20	4928	2561	7489	5100	9.5
1076	20	4764	3106	7870	5481	5.1

Table 10. Forage yield and efficiency of applied nitrogen on native grass over a two year period with all nitrogen applied "late" (June 9, 1969).

Nitrogen rate, kg N/ha	Phosphorus rate, kg P/ha	Forage yield 1969 kg/ha	Forage yield 1970 kg/ha	Total forage yield kg/ha	Total increase over control kg/ha	Efficiency of applied nitrogen, kg forage/ka N
0	0	2377	490	2867		
34	0	2875	427	3302	435	12.8
67	0	3668	758	4426	1559	23.3
135	0	4279	908	5187	2320	17.2
269	0	4670	1200	5870	3003	11.2
538	0	5317	1462	6779	3912	7.3
1076	0	4070	1601	5671	2804	2.6
0	20	1953	382	2335		
34	20	2836	524	3360	1025	30.1
67	20	3919	683	4602	2267	33.8
135	20	4882	1097	5979	3644	27.0
269	20	5932	1808	7740	5405	20.1
538	20	5335	1568	6903	4568	8.5
1076	20	4360	1952	6312	3977	3.7

Table 11. Orthogonal comparisons between fertilizer nitrogen levels as they influenced forage yields during the two year study.

Comparison I		Comparison II	
Comparison	F test	Comparison	F test
AB vs CDEFG[1/]	**	A vs BCDEFG	**
A vs B	+	BC vs DEFG	**
CD vs EFG	**	B vs C	**
C vs D	+	DE vs FG	ns
EF vs G	ns	D vs E	+
E vs F	ns	F vs G	ns

1/ Treatment identification:
A = 0 B = 34 C = 67 D = 135
E = 269 F = 538 G = 1076 kg N/ha

+ Significant at the 0.1 level
** Significant at the 0.01 level
ns Not significant

In addition to being significant, the yield increases between most rates are substantial, increasing the probability of producing economical returns from nitrogen. The nitrogen efficiencies that are shown in Tables 9 and 10 may be used to determine economical returns. The three lowest rates generally showed by far the greatest efficiencies of the applied nitrogen. The greater efficiency at the 67 kg N/ha rate as compared to the 34 kg N/ha rate has considerable implications. The 135 kg N/ha rate has somewhat lower efficiencies at the end of this two year period, but yields from succeeding years must be considered to arrive at the maximum efficiency. Assuming that residual nitrogen will persist longer with each increasing rate of nitrogen applied, the efficiencies of these rates will increase until all residual nitrogen is utilized and the fertilized plots will no longer show increased yields.

In summary, at the end of the two year period maximum nitrogen efficiency occurred at the 67 kg N/ha rate regardless of nitrogen application date or phosphorus application.

Statistical analysis indicated that forage yield was not significantly influenced by phosphorus applied at the rate of 20 kg P/ha. It must be noted, however, that in comparing yields in Tables 9 and 10, only in three out of the twenty-four yields listed are the yields of plots with nitrogen alone greater than their counterparts with 20 kg P/ha applied. In only one case, that of the 67 kg N/ha rate on the "early" application, was the two-year total forage yield greater with nitrogen alone than it was with the application of nitrogen plus phosphorus. On the other hand, where the 20 kg P/ha rate was applied without nitrogen, the yield was decreased.

Tables 9 and 10 indicate considerable increases in yield and efficiency of applied nitrogen when phosphorus was added, but much of these increased yields and efficiencies were credited to the lower yields at the 0 kg N + 20 kg P/ha rate as compared to the control where neither nitrogen nor phosphorus was applied.

If the addition of phosphorus alone upset the N-P balance in the grass enough to actually decrease forage yield, it would be wrong to compare the increased forage yields from the N+P plots to the yields from plots receiving 20 kg P/ha. Rather, these yields should be compared to the control receiving neither nitrogen nor phosphorus. This is done in Tables 12 and 13. This new comparison certainly decreases the efficiency of applied nitrogen where phosphorus was applied, but there still is a slightly greater efficiency of applied nitrogen when phosphorus was applied with it, regardless of date of application.

These observations indicate that perhaps if a greater number of phosphorus rates had been applied, the evaluation of phosphorus might have been more favorable. Certainly more

Table 12. Efficiency of the "early" application of nitrogen over a two year period when applied with phosphorus as compared to the control.

Nitrogen rate, kg N/ha	Phosphorus rate, kg P/ha	Total yield, kg/ha	Increase over control, kg/ha	Efficiency of applied nitrogen, kg forage/kg N applied
0	0	2944		
34	20	3852	908	26.7
67	20	5489	2545	38.0
135	20	6847	3903	28.9
269	20	7760	4816	17.9
538	20	7489	4545	8.4
1076	20	7870	4946	4.6

Table 13. Efficiency of the "late" application of nitrogen over a two year period when applied with phosphorus as compared to the control.

Nitrogen rate, kg N/ha	Phosphorus rate, kg P/ha	Total yield, kg/ha	Increase over control, kg/ha	Efficiency of applied nitrogen, kg forage/kg N applied
0	0	2867		
34	20	3360	493	14.5
67	20	4602	1735	25.9
135	20	5979	3112	23.0
269	20	7740	4873	18.1
538	20	6903	4036	7.5
1076	20	6312	3445	3.2

work needs to be done with phosphorus in this area before a final evaluation is made.

In essence, the date of application study was aimed at determining which grasses -- the cool season or warm season species -- would supply the greatest amounts of forage and protein during the growing season at the most efficient and economical rates.

Early application of nitrogen was aimed at stimulating the cool season species and as the notes indicated (Tables 3 and 7) this was successful in that the majority of the forage growth noted under this system consisted of bluegrass, western wheatgrass, needle and thread, and green needlegrass. These species dominated early in the season, subduing the warm season species that at this time were just initiating their growth. These plots were then cut and the removal of the cool season grasses allowed the warm season understory to become competitive and in the weeks to follow these grasses, consisting primarily of little bluestem, were able to become the dominant form of vegetation on the plots. Bluestem, western wheatgrass and Stipa regrowth made moderate contributions to the stand, but when the second cut was taken, the forage was observed to consist highly of little bluestem, much of it headed out.

By applying nitrogen later (June) it was hoped to stimulate the warm season grasses, which would at this time be ready to initiate growth, without giving the cool season grasses an advantage over them. However, it was recognized that because of the later initiation of growth thus stimulated, it would be possible to take only one cutting quite late in the growing season. The cool season species in these stands were beyond maturation at the time of cutting and therefore were dormant or went dormant after cutting. Only if there had been considerable amounts of late summer rains could there have been any regrowth expected from the warm season grasses.

One problem that might be expected to be encountered in fertilization to stimulate warm season species is that of finding the proper rate. If the rate is too low it cannot be expected to produce efficient yield increases, but on the other hand, a higher rate may allow residual nitrogen to be carried over to the next growing season when the cool season species will pick it up early in the spring before the warm season species are capable of using it. Thus, what was induced to become warm season pasture or hayland one year, becomes a cool season pasture the next.

A possible solution to this problem might be to attempt to find the most efficient rate of nitrogen from the forage production standpoint and then when the cool season species begin to take over the stands in early spring before the warm season grasses begin to grow, graze the pastures until the warm season species begin to emerge. Then remove the livestock, fertilize, and allow the warm season grasses to grow uninterrupted until later in the season when they are needed.

It might be stressed that the most efficient rate of applied nitrogen may not be the most desirable from an economic standpoint. The most economical rate will be determined by the forage cost:beef price ratio. The forage yields for both application dates are shown in Tables 9 and 10.

Statistical analysis indicated that date of application was not significant in the production of forage.

Crude Protein Analysis

"Early" application of nitrogen - 1969

Although Fig. 13a indicates a slight decrease in protein yield in the second cutting as compared to the first, the analysis of variance did not show a significant difference (.05 level) between cuttings.

Phosphorus application at 20 kg P/ha significantly increased protein yields at the 0.1 level. Fig. 13a indicates that the greater part of this increase was at higher rates of applied nitrogen, however, the nitrogen x phosphorus interaction was nonsignificant. Protein concentrations were not greatly influenced by phosphorus application (Fig. 13b).

The application of nitrogen accounted for highly significant (.01 level) increases in protein yield. Two separate orthogonal comparisons were run in addition to the analysis of variance in order to determine which rates

Fig. 13. Protein yield and protein concentration in two 1969 cuttings as affected by phosphorus application, and various rates of nitrogen when nitrogen was applied "early".

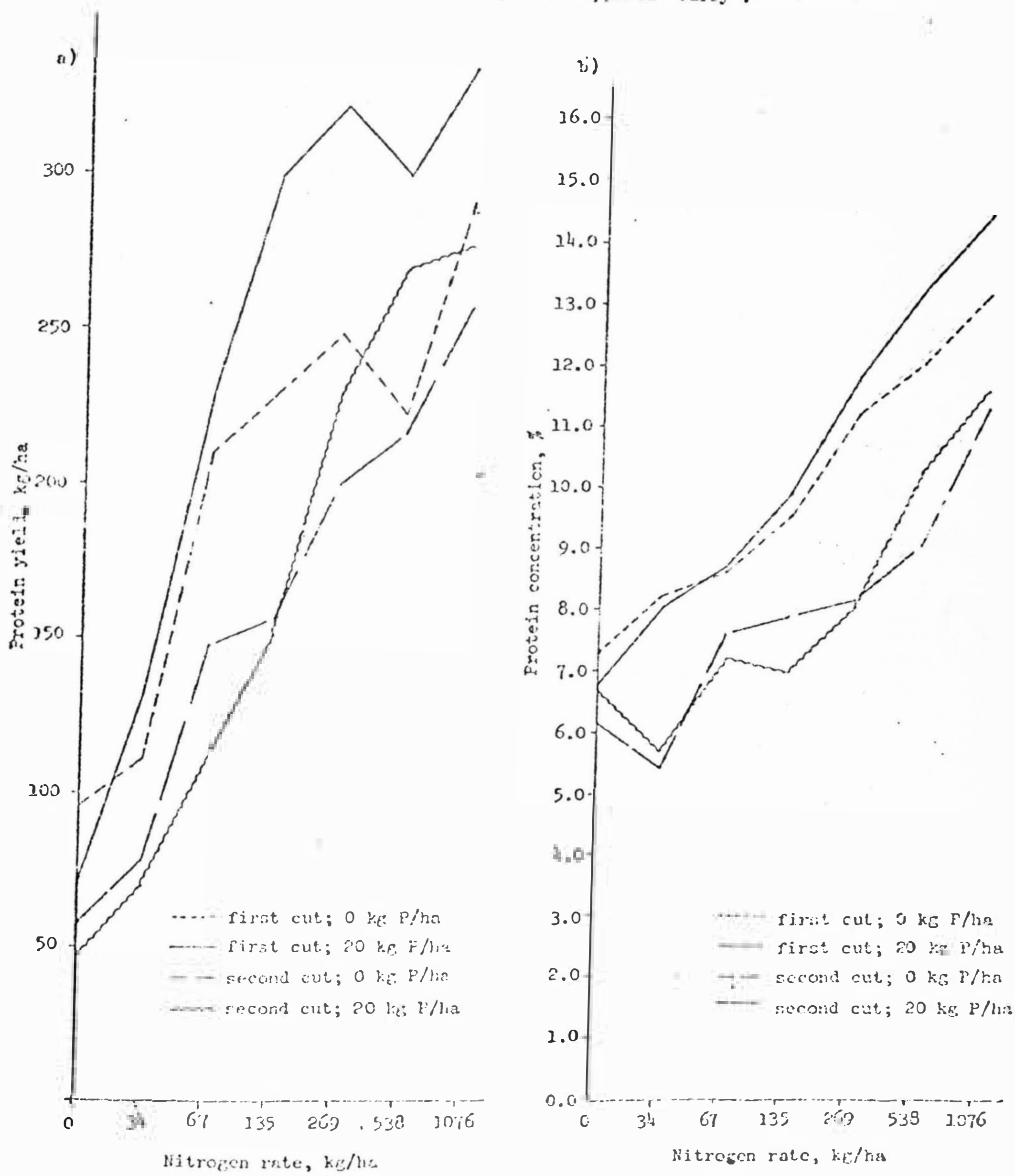


Table 14. Orthogonal comparisons of fertilizer nitrogen levels as they influenced protein yield in two cuts of the "early" plots.

Comparison I		Comparison II	
Comparison	F test	Comparison	F test
AB vs CDEFG[1/]	**	A vs BCDEFG	**
A vs B	ns	BC vs DEFG	**
CD vs EFG	**	B vs C	*
C vs D	ns	DE vs FG	*
EF vs G	ns	D vs E	ns
E vs F	ns	F vs G	ns

1/ Treatment identification:
A = 0 B = 34 C = 67 D = 135
E = 269 F = 538 G = 1076 kg N/ha

* Significant at the .05 level
** Significant at the .01 level
ns Not significant

of nitrogen produced significant yield differences (Table 14). Comparisons I and II shows that only in one case was there a significant increase in protein yield between any two levels, and this was between the 34 kg N/ha and the 67 kg N/ha rates. In all other cases where significance was shown, the comparisons are grouped comparisons. Certainly the graphs in Fig. 13 display the magnitude of the response nitrogen induced in both protein concentration and protein yield.

"Early" application of nitrogen - 1970

In 1970 the residual of the 67 kg N/ha rate doubled protein yield (Fig. 14a). Protein yield also increased with increasing rates of nitrogen above the 67 kg N/ha rate.

Protein concentration (Fig. 14b) showed little increase at the lower nitrogen rates, but increased considerably at the higher ones.

"Late" application of nitrogen - 1969 and 1970

As with forage yield, protein yield (Fig. 15a) was greatly reduced in 1970 due to the greater moisture stress. All of the 1970 protein yields were less than 25% of the 1969 yields except at the 1076 kg N/ha rate which was recovering from the salt and burning damage suffered in the first year. The lower rates showed very slight increases in 1970. Protein concentration (Fig. 15b) increased at each increment of nitrogen in 1969, but in 1970 the concentration was very similar for the control and the 34, 67, and 135

Fig. 14. Protein yield and protein concentration in 1970 as affected by residual phosphorus and residual nitrogen at various rates when applied "early".

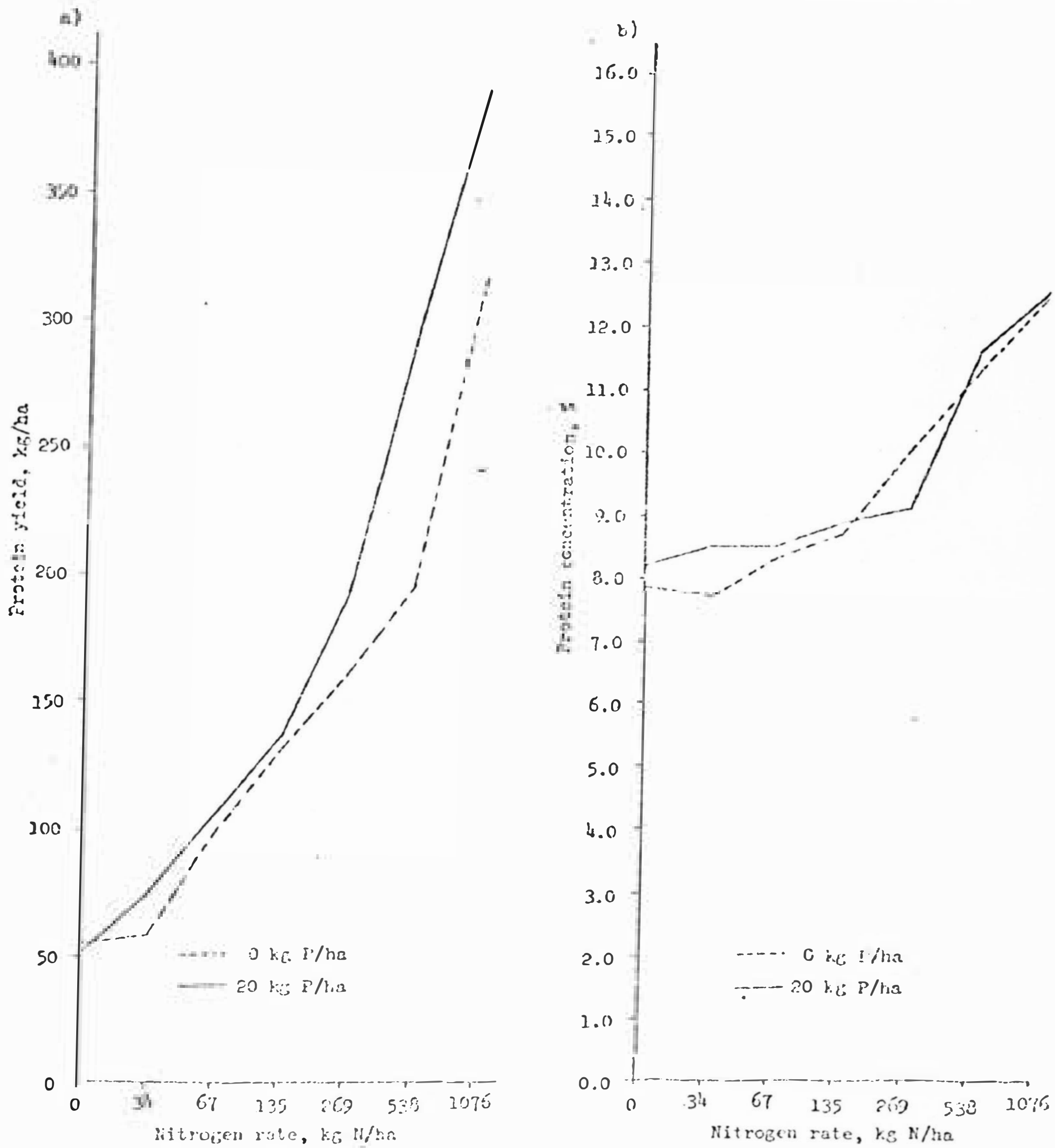
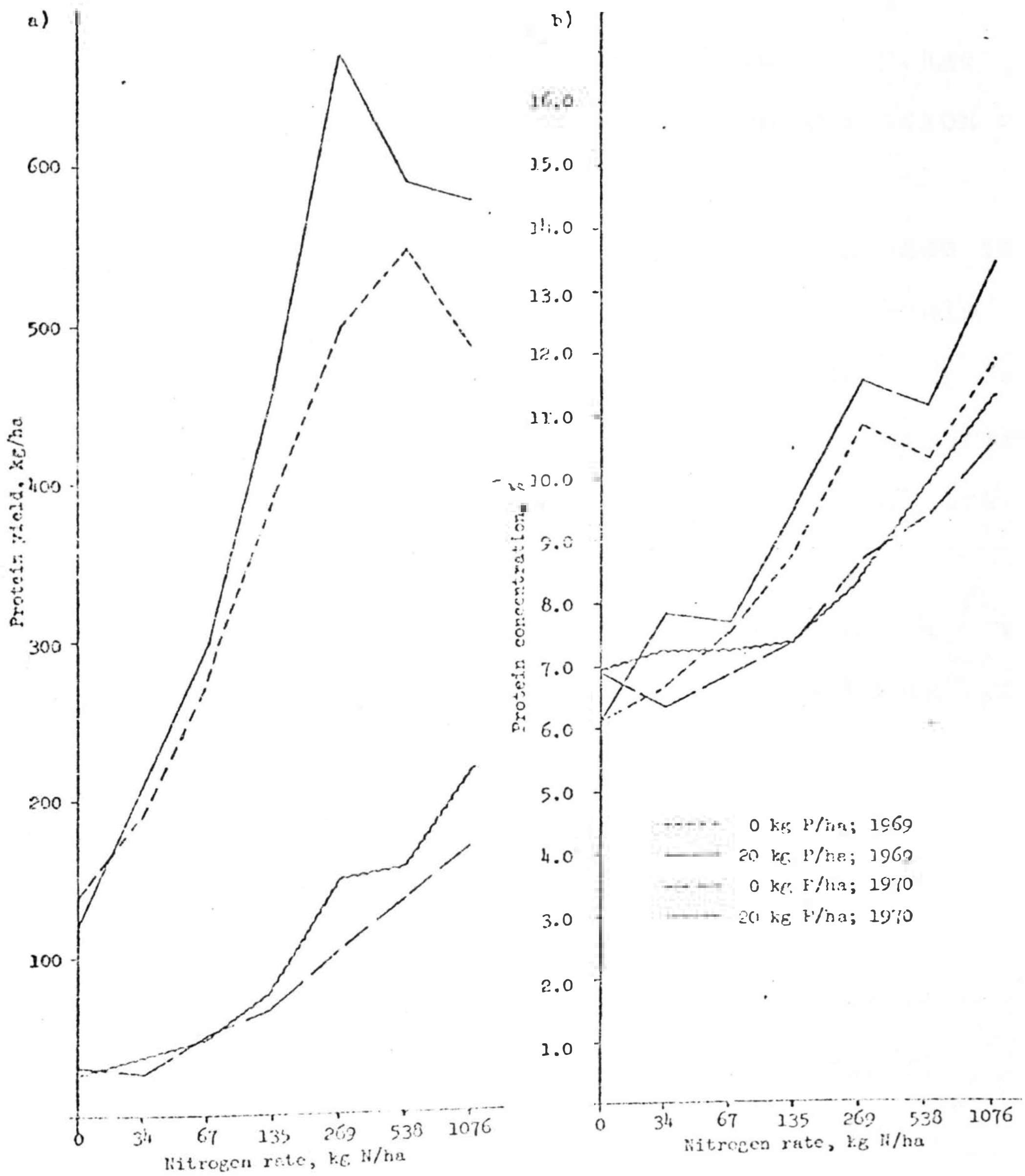


Fig. 15. Protein yield and protein concentration in 1969 and 1970 as affected by phosphorus and various nitrogen rates when applied "late".



kg N/ha rates. It then started to increase at higher rates.

Statistical analysis of protein yield for the entire experiment

The analysis of variance for protein yield showed that a highly significant difference (.01 level) occurred between years. This can be credited mainly to the lower forage yields in 1970 rather than from decreased concentration of protein in the forage (Fig. 13, 14, and 15).

Phosphorus did not produce a significant increase in protein yield over the two year period. However, Table 15 seems to show some trends at both application dates in favor of phosphorus application, again indicating that more research should be carried out with phosphorus before a final evaluation is made.

Nitrogen produced highly significant increases in protein yield, and two orthogonal comparisons were made to determine which rates produced significant increases (Table 16). It was found that the 34 kg N/ha rate did not produce a significant increase over that of the control, nor was there a significant increase produced between the 269 and 538 kg N/ha rates, but in all other comparisons made, each increasing rate of nitrogen produced a significant or highly significant increase in protein yield. Date of nitrogen application did not produce a significant difference in protein yield.

These data concerning the effects of nitrogen fertilization on protein concentration and protein yield are consistent with findings reported by Smoliak (33) and Cosper and Thomas (8).

Table 15. Total protein yield in two growing seasons as affected by varying levels of applied nitrogen, date of nitrogen application, and application of phosphorus.

		Protein yield (1969 + 1970)			
		"Early" nitrogen application		"Late" nitrogen application	
Nitrogen rate, kg N/ha	Phosphorus rate, kg P/ha	Total, kg/ha	Increase over control, kg/ha	Total, kg/ha	Increase over control, kg/ha
0	0	209		175	
34	0	246	37	217	42
67	0	455	246	331	156
135	0	515	306	460	285
269	0	609	400	605	430
538	0	635	426	685	510
1076	0	866	657	656	481
0	20	170		153	
34	20	274	104	250	97
67	20	440	270	349	196
135	20	584	414	543	390
269	20	743	573	824	671
538	20	868	698	750	597
1076	20	1003	833	801	648

Table 16. Orthogonal comparisons between fertilizer nitrogen levels as they influenced protein yields during the two year study.

Comparison I		Comparison II	
Comparison	F test	Comparison	F test
AB vs CDEFG[1/]	**	A vs BCDEFG	**
A vs B	ns	BC vs DEFG	**
CD vs EFG	**	B vs C	**
C vs D	**	DE vs FG	**
EF vs G	**	D vs E	**
E vs F	ns	F vs G	*

1/ Treatment identification:

A = 0 B = 34 C = 67 D = 135

E = 269 F = 538 G = 1076 kg N/ha

* Significant at the .05 level

** Significant at the .01 level

ns Not significant

Plant Phosphorus Analysis

"Early" application of nitrogen - 1969 and 1970

Analysis of variance on the two 1969 cuttings of the "early" application of nitrogen in 1969 showed that phosphorus fertilization (Fig. 16) produced a highly significant (.01 level) increase in plant phosphorus concentration. Also, phosphorus yield was found to be significantly (.05 level) increased by phosphorus application. There was no significant difference in phosphorus concentration between cuttings in 1969.

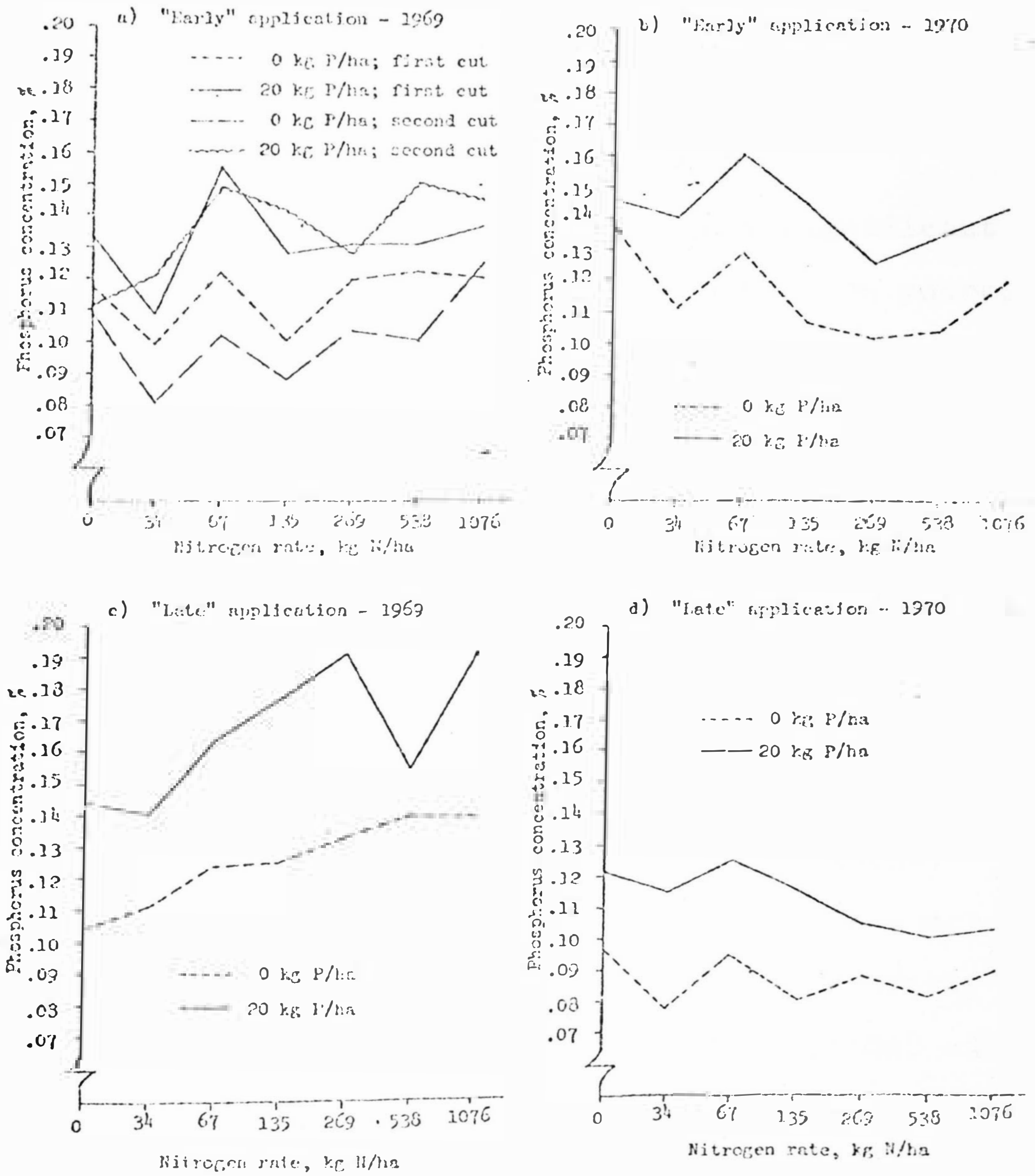
In the 1969 analysis (Figs. 16a and 16b), nitrogen increased plant phosphorus concentration significantly at the .05 level. Increases in phosphorus yield (Table 17) due to nitrogen applications were highly significant (.01 level).

In a separate analysis of the 1970 data, residual phosphorus from the 20 kg P/ha application was still found to account for highly significant (.01 level) increases in plant phosphorus concentration as illustrated in Fig. 16. However, residual nitrogen significantly increased phosphorus concentration only at the .1 level.

"Late" application of nitrogen - 1969 and 1970

The analysis of variance for plant phosphorus concentration for the "late" application of nitrogen showed that phosphorus fertilization produced highly significant

Fig. 16. Plant phosphorus concentration as affected by nitrogen rate, date of nitrogen application, and application of phosphorus.



(.01 level) increases in phosphorus concentration as illustrated in Fig. 16. The analysis of variance also showed a highly significant difference in years with respect to plant phosphorus concentration, but no significant difference was found for nitrogen application.

Statistical Analysis of Phosphorus Yield
For the Entire Experiment

Analysis of variance indicated a highly significant (.01 level) difference in phosphorus yield between years, while the 20 kg P/ha application accounted for differences significant only at the .05 level.

Nitrogen application accounted for highly significant increases in phosphorus yield (Table 17). Orthogonal comparisons, when made between each rate and all higher rates combined, showed significant or highly significant increases in phosphorus yield with increasing nitrogen rates up through the 269 kg N/ha rate.

Date of nitrogen application was not significant. Table 17 shows that recovery of applied phosphorus increased considerably with nitrogen application and was generally greatest at the four highest nitrogen rates. Without added nitrogen, very little phosphorus was recovered.

Plant Potassium Analysis

"Early" application of nitrogen - 1969

Analysis of variance of the potassium concentrations

Table 17. Total phosphorus yield and recovery in two growing seasons as affected by varying levels of applied nitrogen, date of nitrogen application, and application of phosphorus.

Nitrogen rate, kg N/ha	Phosphorus yield with 0 kg P applied/ha, kg P/ha (1969) (1970) (total)	Phosphorus yield with 20 kg P applied/ha, kg P/ha (1969) (1970) (total)	Difference, kg P/ha	Recovery of applied phosphorus, %
"Late"				
0	2.66 + 0.51 = 3.17	3.05 + 0.51 = 3.56	0.39	1.95
34	3.27 + 0.33 = 3.60	4.04 + 0.64 = 4.68	1.08	5.40
67	4.53 + 0.71 = 5.24	6.37 + 0.86 = 7.23	1.99	9.95
135	5.49 + 0.73 = 6.22	8.66 + 1.27 = 9.93	3.71	18.55
269	6.31 + 1.04 = 7.35	11.21 + 1.89 =13.10	5.75	28.75
538	7.39 + 1.18 = 8.57	8.21 + 1.57 = 9.78	1.21	6.05
1076	5.65 + 1.43 = 7.08	8.31 + 1.99 =10.30	3.22	16.10
"Early"				
0	2.59 + 0.95 = 3.54	2.35 + 1.00 = 3.35	- 0.19	
34	2.38 + 0.78 = 3.16	3.44 + 1.12 = 4.56	1.40	7.00
67	4.67 + 1.50 = 6.17	6.74 + 1.85 = 8.59	2.42	12.10
135	4.19 + 1.59 = 5.78	7.03 + 2.21 = 9.24	3.46	17.30
269	4.81 + 1.69 = 6.50	7.90 + 2.66 =10.56	4.06	20.30
538	4.34 + 1.84 = 6.18	7.02 + 3.54 =10.56	4.38	21.90
1076	5.23 + 3.10 = 8.33	6.79 + 4.45 =11.24	2.91	14.55

graphed in Fig. 17a showed there was no significant difference in concentrations between cuttings. Phosphorus fertilizer did not significantly influence potassium concentration. Nitrogen caused highly significant (.01 level) increases in potassium concentration, although two separate orthogonal comparisons showed no significant increases between any two adjacent rates of nitrogen.

"Late" application of nitrogen - 1969 and 1970

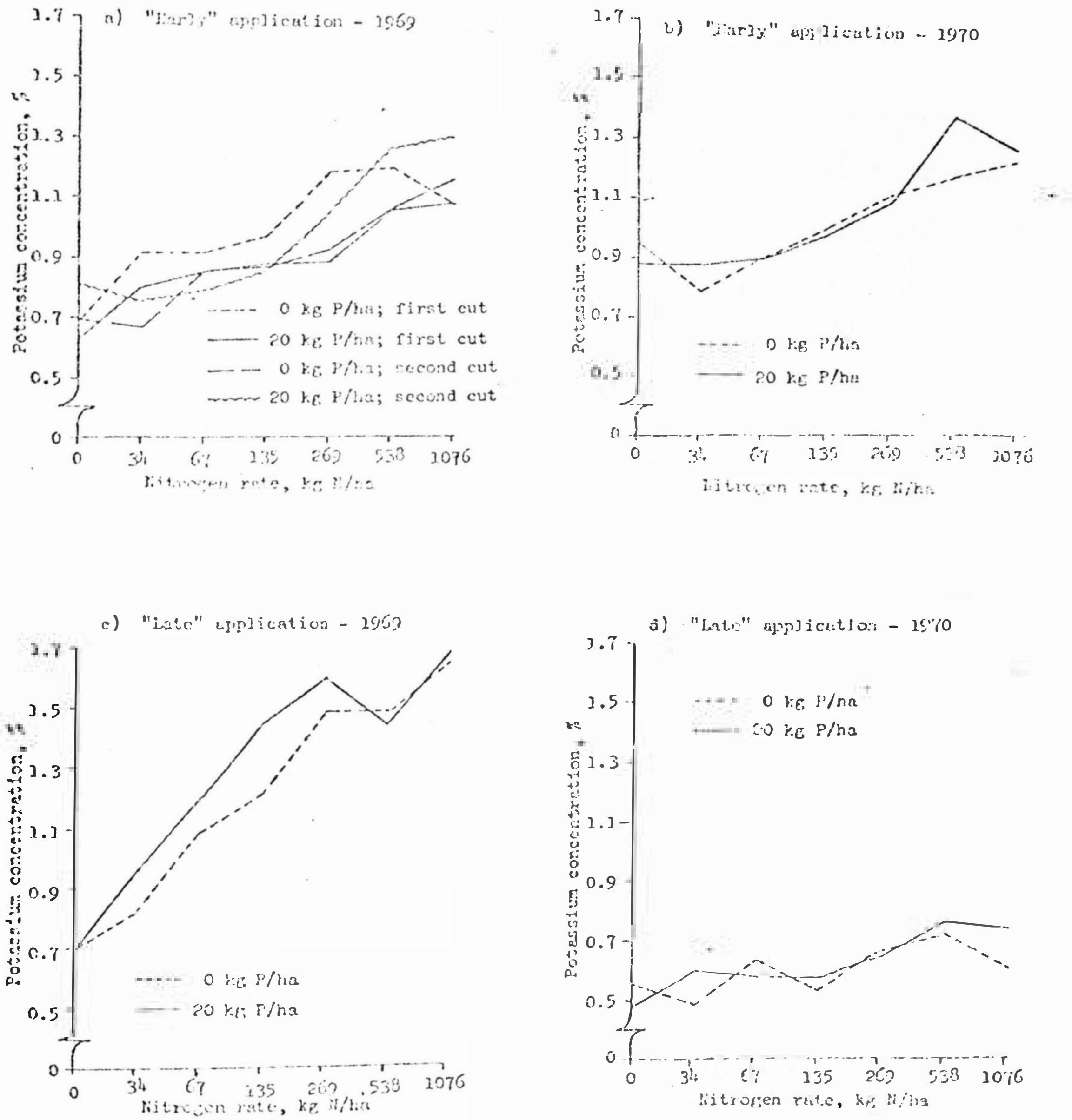
Analysis of variance of the data presented in Figs. 17c and 17d showed the decrease in potassium concentration in the second year was highly significant (.01 level). Nitrogen produced a highly significant increase in potassium concentration despite the nearly horizontal graph in Fig. 17d. However, the nitrogen by year interaction was highly significant.

Phosphorus produced a highly significant increase in potassium concentration despite the appearance of the graphed data (Figs. 17c and 17d).

"Early" and "late" application of nitrogen - 1970

Analysis of variance of the 1970 data showed that the lower concentration of potassium in the "late" application forage as compared to the "early" application, was highly significant (.01 level). However, it must be remembered that the "late" application forage was cut six weeks later than the "early" application, and during this time moisture

Fig. 17. Plant potassium concentration as affected by nitrogen rate, date of nitrogen application and application of phosphorus.



stress was quite severe. Phosphorus did not significantly affect potassium concentration in 1970, but nitrogen produced highly significant increases.

Plant Nitrate Analysis

Nitrates are converted to toxic nitrites in the rumen of cattle and sheep and in the caecum of horses, and these nitrites combine with hemoglobin to form methemoglobin which is incapable of carrying oxygen (34). The end result is asphyxiation of the animal.

Forage containing less than 1500 ppm NO_3-N is considered to be safe to feed under all conditions; that containing between 1500 and 3000 ppm NO_3-N safe when limited to one-half the daily dry matter intake; that containing 3000 to 4500 ppm NO_3-N safe when limited to one-fourth the daily dry matter intake; and that containing over 4500 ppm NO_3-N is potentially toxic (34).

Due to the application of several very high rates of nitrogen in this experiment, it was considered probable that toxic concentrations of nitrate-nitrogen might accumulate in the plant tissue.

Nitrate-nitrogen concentrations were determined on the first cut forage of the "early" nitrogen application without phosphorus and on the "late" nitrogen application without phosphorus in 1969. In 1970, all samples were analyzed for nitrates. The results appear in Table 18 and although nitrate

Table 18. Concentration of nitrate-nitrogen in native grass forage cut in two growing seasons as affected by various rates of applied nitrogen, date of nitrogen application, and application of phosphorus.

Nitrogen rate, kg N/ha	Phosphorus rate, kg P/ha	1969 "Early" application, ppm NO_3-N	1969 "Late" application, ppm NO_3-N	1970 "Early" application, ppm NO_3-N	1970 "Late" application, ppm NO_3-N
0	0	185	82	59	121
34	0	151	82	146	125
67	0	136	115	71	142
135	0	160	98	75	125
269	0	229	492	105	169
538	0	342	561	238	291
1076	0	525	1330	556	431
0	20			75	123
34	20			75	107
67	20			92	142
135	20			70	142
269	20			121	167
538	20			297	288
1076	20			743	346

levels increase at the higher nitrogen rates, all levels are in the "safe" range.

Plant Calcium Analysis

Plant calcium was determined on all samples in 1970 only. Analysis of variance of the calcium concentration data illustrated in Fig. 18 showed that phosphorus fertilizer did not cause any significant differences in calcium concentration. However, the forage from the "late" application was significantly (.05 level) lower in calcium than that of the "early" application.

The decrease in calcium concentration with increasing nitrogen rate as illustrated in Fig. 18 was highly significant (.01 level). This is consistent with findings by Smoliak (33). Orthogonal comparisons indicated the significant concentration decreases were obtained when the control and the 34 kg N/ha rate were compared to the rest of the rates as might be assumed from observing Fig. 18.

Cattle, sheep and horses do not need more than 0.2 or 0.3 percent calcium in their rations on an air dry basis (23) except in the case of very young animals. In no case did nitrogen fertilization decrease calcium concentration to these levels in this experiment (Fig. 18).

Plant Magnesium Analysis

As with calcium, plant magnesium concentrations were determined for the 1970 harvest samples. The data are

Fig. 18. Plant calcium concentration as affected by nitrogen rate, date of application, and application of phosphorus.

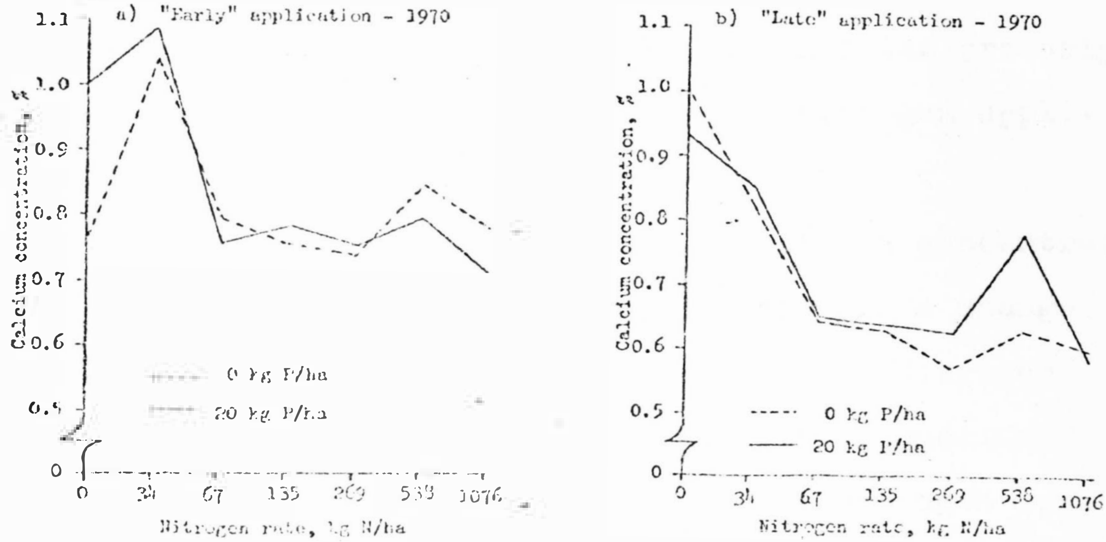
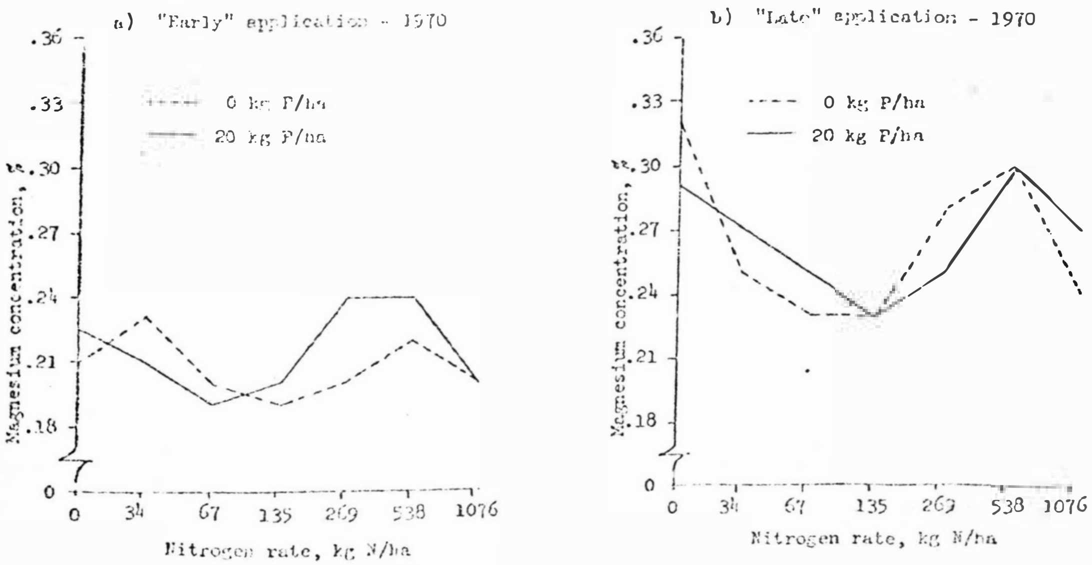


Fig. 19. Plant magnesium concentration as affected by nitrogen rate, date of application, and application of phosphorus.



graphed in Fig. 19. Statistical analysis of the data showed that there was a significant difference (.05 level) in magnesium concentration of the forage between the "early" and "late" application of nitrogen. The "early" harvest contained lower magnesium levels. Again, this was probably due to date of cutting rather than date of nitrogen application.

Phosphorus did not significantly affect the concentration of magnesium (Fig. 19), but nitrogen did produce a change in concentration significant at the .05 level. Nitrogen rates produced an interesting relationship to magnesium concentrations. As increasing increments of nitrogen were applied, magnesium concentrations decreased until 269 kg N/ha had been applied when magnesium concentration began increasing again. As more native grasslands are fertilized with nitrogen this relationship may need to be studied in detail to find if it is important in nutrition of livestock.

Plant Sulfur Analysis

Sulfur concentrations were determined on the second year forage only. Statistical analysis showed that applied nitrogen, applied phosphorus and date of nitrogen application had no effect on sulfur concentrations. Concentrations ranged from a low of 0.040% to a high of 0.114%.

SUMMARY AND CONCLUSIONS

A field study was run two years at the Pasture Research Center in Faulk County, South Dakota, to determine the effects of fertilizer phosphorus, fertilizer nitrogen, and date of nitrogen application on forage yield, crude protein and phosphorus content, potassium, calcium, magnesium, sulfur and nitrate-nitrogen concentrations of native grass.

Nitrogen application produced highly significant increases in forage yield. Orthogonal comparisons indicated the greatest increase was between the 34 kg N/ha and 67 kg N/ha rates which was the only highly significant yield increase between two adjacent rates. The 34 kg N/ha rate produced a significant forage yield increase in the analysis of the two 1969 "early" cuts, but in the overall analysis, this rate produced increases significant only at the .1 level.

Nitrogen application also produced highly significant (.01 level) increases in crude protein yield during the study due to the higher total forage yields on nitrogen fertilized plots and also considerably increased protein concentration with increasing rates of nitrogen. However, orthogonal comparisons showed that there were no significant increases in crude protein yield when the 34 kg N/ha rate was applied. Protein yields were not increased significantly between the 269 kg N/ha and 538 kg N/ha rates. All other adjacent rates showed significant (.05 level) or highly significant (.01 level) increases in protein yield when nitrogen rate was doubled.

Nitrogen application produced a highly significant increase in plant phosphorus yield and greatly increased the recovery of applied phosphorus. Without added nitrogen, almost none of the applied phosphorus was recovered in the forage.

Nitrogen application produced a highly significant increase in plant potassium concentration. Nitrogen application produced a highly significant decrease in calcium concentration. Sulfur concentration varied without regard to fertilizer nitrogen application. Magnesium concentration decreased with moderate rates of nitrogen and increased again at the three highest rates of nitrogen.

Analysis of the forage indicated that nitrate-nitrogen in the native grass did not reach toxic levels even at the highest rate of applied nitrogen, 1076 kg N/ha, or under severe drought conditions in the second year.

Visual evaluation indicated that western wheatgrass, smooth bromegrass, and weed species including primarily Japanese chess and Flodman's thistle increased with increasing nitrogen rates.

Phosphorus, applied at the rate of 20 kg P/ha, did not significantly increase forage yields or protein yields during the two year study although protein yield was increased significantly at the .1 level in the 1969 cuttings of the "early" application of nitrogen. However, phosphorus application caused highly significant (.01 level) increases in plant phosphorus concentration and significant (.05 level) increases in plant phosphorus yield in the two year period. Plant potassium was not significantly influenced by phosphorus in either year on the "early" nitrogen application, and showed very little difference on the "late" nitrogen application. Residual phosphorus did not significantly influence sulfur, magnesium, and calcium concentrations.

Date of nitrogen application was not a significant factor in determining forage, crude protein, or phosphorus uptake in the overall analysis. For the statistical analysis of the 1970 harvest, calcium, magnesium, and phosphorus concentrations were significantly affected at the .05 level and potassium at the .01 level by dates of nitrogen application.

In conclusion, this experiment has shown that nitrogen fertilization can increase forage yields in this part of the Great Plains. Subnormal precipitation during the study in itself lends strength to the supposition that significant and substantial yield increases can be obtained with nitrogen fertilization over a period of years.

Date of nitrogen application may not have shown significant yield or protein increases, but we can conclude that the rancher can expect yield increases from applied nitrogen on his warm season pastures as well as on his cool season

Phosphorus may have shown no significant yield or protein increases, but trends indicated that more work must be done with phosphorus before making a final evaluation.

The data presented here appear to have considerable practical value, although it will vary with the fertilization cost:cattle price ratio.

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APPENDIX I

Photographs of the forage collector used to collect grass samples. The collector was built onto a Haban flail mounted to a Model 112 John Deere garden tractor.

Appendix I

Front view of flail adaption. All forage is removed through the front door. Note that the old residue is not picked up.

Appendix I (continued)

Side view of the adaption with the side panel removed. Note that the forage is blown to the front of the collection cage.